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1991

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Foreword

During 1991, the Ontario Geological Survey carried out independent detailed, regional and province-wide compilation geoscience studies throughout the province. In addition, projects were undertaken in co-operation with personnel from the Mines and Minerals Division, other Ministries and governments, universities and private consulting firms. Individual reports indicate if a project has special funding or non-Ontario Geological Survey participants.

A major effort of the Survey in 1991 was the final compilation, editing and production of the *Geology of Ontario* project. The project, to mark the centennial of the Ontario Geological Survey, is a major new synthesis of the province's geology presented in a 1200-page volume, and 7 map themes at a scale 1:1 000 000. As of the end of 1991, the Bedrock Geology, Quaternary Geology, Shaded Image of the Total Magnetic Field, Vertical Magnetic Gradient, Bouger Gravity and Vertical Gravity Gradient map themes and the first half of the volume will have been released. The second half of the volume, the Tectonic Assemblages map theme and a brief "popularized" version of the volume are scheduled for release in 1992.

The locations of the areas investigated in 1991 are compiled on a map of the province at the beginning of this report. Highlights of preliminary results of field work and other activities are summarized by Section Chiefs and more extensive reports have been prepared by leaders and principal investigators for each of the projects. The aim of the Ontario Geological Survey in producing this summary, immediately following the field season, is to provide quick access to new information for these areas, which will be of immediate value in mineral exploration and land capacity planning. In addition, the wide spectrum of research in this report is of interest to the geoscience community as a whole.

Survey geoscientists will conduct more detailed research and analysis of the field data through the winter and will be preparing reports on these investigations for publication. In the interim, uncoloured maps will be released as open files; open file maps and reports are available at the Mines Library, 77 Grenville Street, Toronto, or at Ministry of Northern Development and Mines regional offices. Notices of these releases will be mailed out to all persons or organizations on the Mines and Minerals Division publications release notification list, and selected releases may be publicized in technical journals and other media.

V.G. Milne
Director, Geoscience Branch
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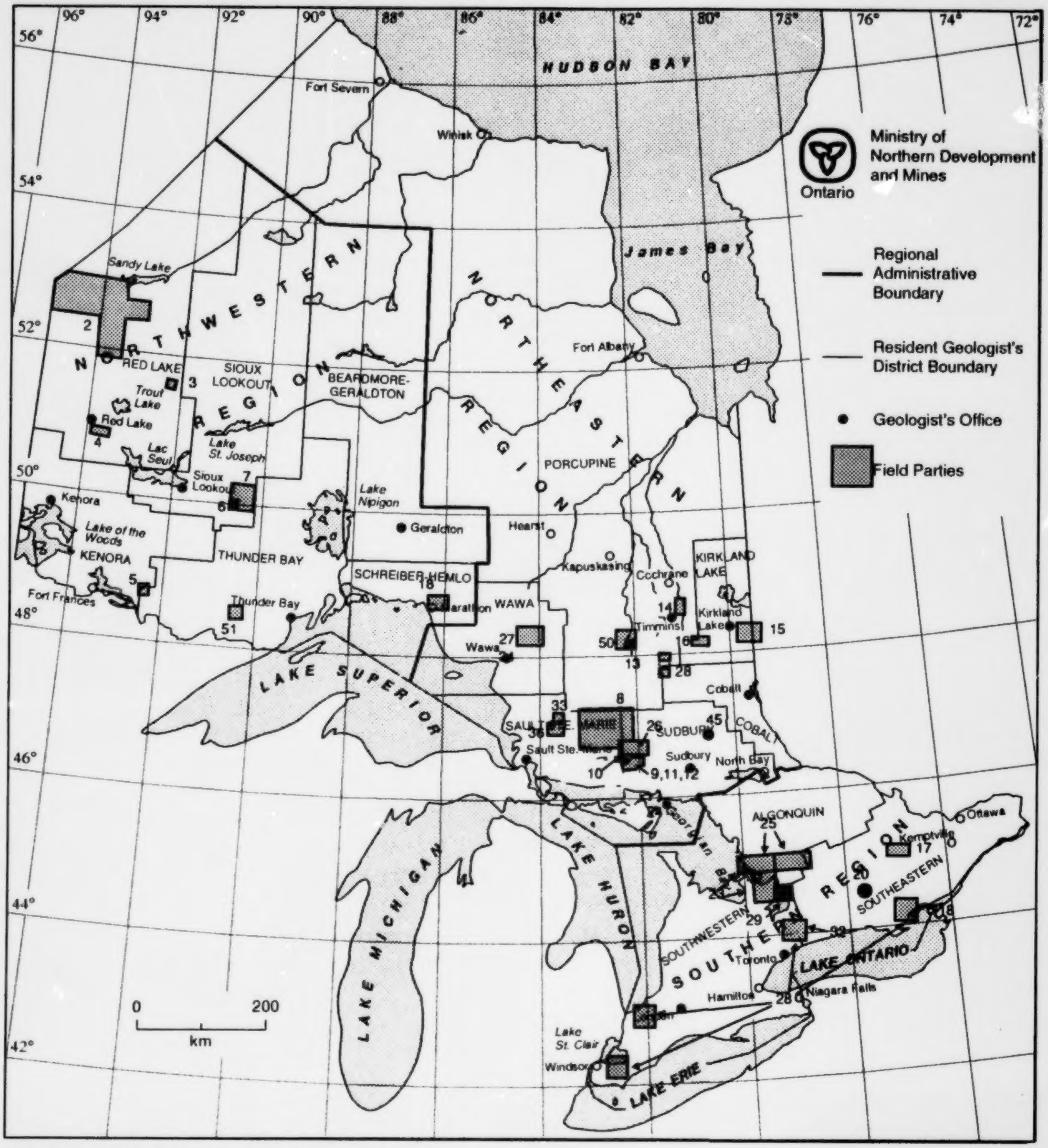
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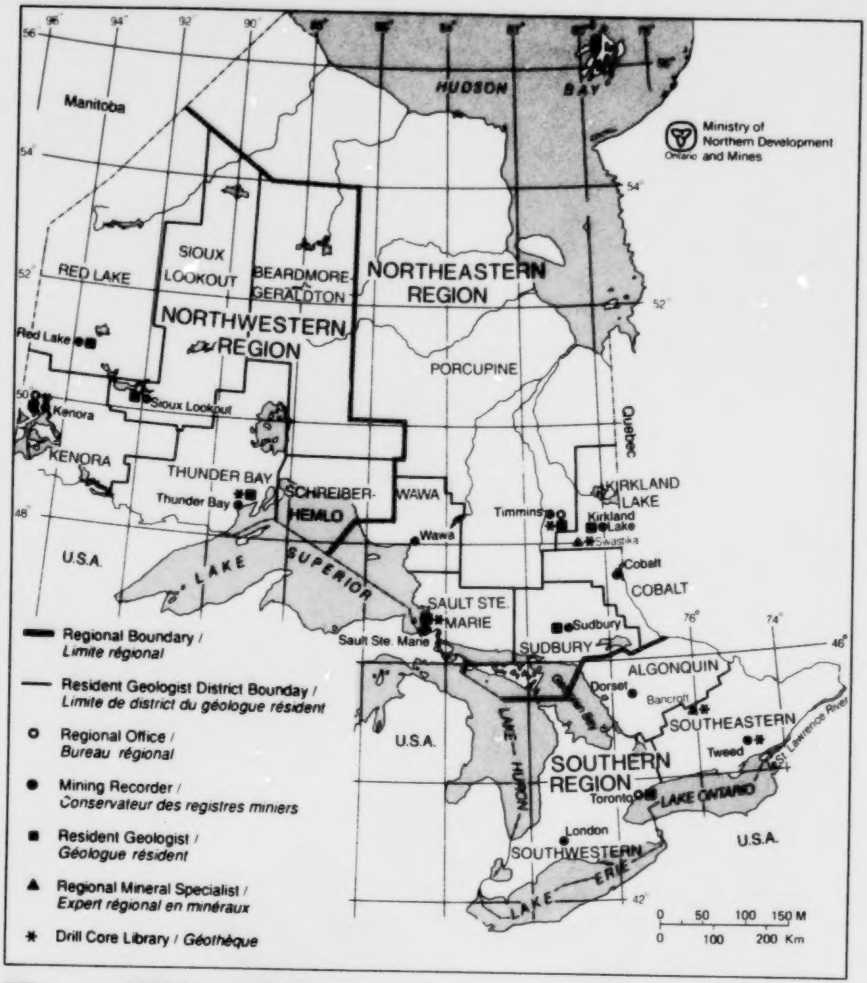
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Precambrian Geology Programs

1. Summary of Activities 1991, Precambrian Geology Section

B.O. Dressler

Acting Chief Geologist, Precambrian Geology Section, Ontario Geological Survey

INTRODUCTION

In 1991, the Precambrian Geology Section program emphasized detailed and regional mapping projects in conjunction with a small number of thematic studies. Detailed mapping was complemented by two externally funded projects. One project was carried out by a geological consulting firm.

MAPPING PROGRAM

Fifteen bedrock mapping projects operated in various regions of the Precambrian Shield of Ontario. This represents a considerable increase compared to the 1990 activities.

In northwestern Ontario, Denver Stone continued regional mapping of granitic terrain and greenstones of the Berens River Subprovince north of Red Lake at a scale of 1:50 000 to 1:100 000. Over the last five years Stone's investigations have led to a greatly improved understanding of the subprovince and its mineral potential. A variety of lobate to irregularly shaped sodic and potassic granitic intrusions have been identified and their tectonic relationships with greenstone assemblages has been investigated.

Gary Beakhouse completed the detailed mapping of the Casummit Lake area within the Birch Lake greenstone belt at a scale of 1:15 840. The Argosy Mine on Casummit Lake produced approximately 100 000 ounces of gold and the area has potential for the discovery of additional precious metal deposits.

Tom Muir, also in northwestern Ontario, began a 2 to 3 year detailed, 1:15 840 scale mapping project of the Dixie Lake area south of Red Lake. This area is presently experiencing mineral exploration activity. Bill Shanks mapped the Wild Potato Lake area east of Fort Frances along the Quetico Fault at a detailed scale of 1:15 840 and reports several small mineral occurrences.

In the Sturgeon Lake area, two mapping projects were conducted, one at a regional scale of 1:50 000, the other at 1:15 840 scale. In the regional project by Howard Williams, emphasis is on a lithostratigraphic-tectonic compilation and examination of regional scale structural and correlation problems, to aid mineral exploration in an area experiencing several mine closures. The project represents a continuation of the 1990 studies by Mary Sanborn-Barrie. The detailed mapping, of the Six Mile Lake area located within the area investigated by Howard Williams, was carried out on contract by A.C.E. Howe International Limited under the leadership of D. Robinson.

Ikram Osmani spent the 1991 field season in Moss Township west of Thunder Bay mapping at a scale of 1:15 840. The project is the first of what is anticipated to be three 2 to 3 year projects planned to investigate parts of the Shebandowan greenstone belt. The greenstone belt hosts several mineral occurrences and is presently experiencing exploration activity.

In northeastern Ontario, Murray Rogers assumed responsibility for the detailed 1:15 000 scale mapping of the Whiskey Lake area east of Elliot Lake concentrating on the Archean supracrustal rocks. In 1990, L.S. Jensen recognized a calc-alkalic volcanic complex with associated mineralization in the area. Murray Rogers completed the mapping of the Whiskey Lake area and commenced mapping a small Archean greenstone terrain between Flack Lake and the

Quirke Syncline north of Elliot Lake. In collaboration with Murray Rogers, staff of the Geology Department of Laurentian University continued work on two projects in the Elliot Lake area. One project deals with the mineral potential of mafic and ultramafic rocks of the Elliot Lake area, the other with the geochemistry of the Whiskey Lake greenstone belt. Both projects are funded by the Ministry of Northern Development and Mines.

North of the two areas investigated by M. Rogers, Fred Breaks began a 1:50 000 scale, regional mapping program of the southern Algoma Granitic Domain. This program will explore an area of the Superior Province in Ontario of which very little is presently known. It may result in re-assessment of large scale tectonic subdivisions.

In the Swayze greenstone belt of the Abitibi Subprovince, Georgio Siragusa continued detailed investigations of gold mineralization associated with a regional deformation zone, which may represent an extension or a splay of the Destor-Porcupine Fault, and John Ayer began a three year, 1:15 840 scale mapping project which will cover approximately ten townships. The program commenced with a study of Foyelet, Ivanhoe, Keith and Muskego townships.

In the Kirkland Lake-Larder Lake-Matachewan area, three mapping projects were carried out in 1991. Steve Jackson completed 1:50 000 scale mapping and a study of the stratigraphy and structural geology of the Kirkland Lake-Larder Lake area. Ben Berger investigated Gowan and Hoyle townships. These two townships are characterized by very little outcrop and Berger's map is based in large parts on the study of drill cores made available by various mineral exploration companies and on the interpretation of geophysical data. Several more townships in the Abitibi Subprovince characterized by very little outcrop will be investigated in a similar manner in future years. Near Matachewan, Dave Kresz mapped Baden and Argyle townships near a recent base metal discovery in Robertson Township.

In southern Ontario, R.M. Easton continued detailed and semi-detailed, 1:15 000 to 1:50 000 scale mapping of the Central Metasedimentary Belt of the Grenville Province. Easton's investigations have led to a much better understanding of the complex geology and mineralization environments of the Grenville Province in Ontario.

THEMATIC STUDIES

Several thematic investigations conducted by staff of the section are nearing completion. Ron Sage is working on a synoptic study of the Michipicoten greenstone belt and Kevin Heather is completing work on the metallogeny of the Mishibishu and Michipicoten greenstone belts. Sage's and Heather's investigations represent final syntheses on several detailed projects on the geology and mineral deposits of the Wawa area which were carried out by the Precambrian Geology Section over the last decade.

Maurice Carter began a geochemical study and compilation of Timiskaming metavolcanic rocks of the Superior Province as part of an investigation of the depositional and mineralization environments of Timiskaming supracrustal works.

GEOLOGY OF ONTARIO PROJECT

Involvement by most staff of the Precambrian Geology section on this multi-year project is largely completed.

A bedrock geology map at a scale of 1:1 000 000 was released in March of this year and is amongst several map types and a comprehensive volume that are scheduled for publication in 1991 or early 1992, marking the centenary of the Ontario Geological Survey. The maps and volume will provide an overview of the geology, mineral deposits and lithotectonic framework of the Precambrian Shield and the Phanerozoic lowlands of Ontario based on 100 years of geological investigations by the Ontario Geological Survey and its predecessors.

DIGITAL MAPPING AND DATA STORAGE

Over the past few years progress has been achieved in developing "OGS FIELDLOG", a cartographic software package integrated with database software. Several staff members of the section are presently using "OGS FIELDLOG" which is designed to archive field notes and facilitate map production.

In 1991, Grant Troop and Richard Cherer continued developments in field note computerization through testing of custom software for use in a lightweight, "pen based", handheld data recording product which will allow "OGS FIELDLOG" data input on traverse, hopefully eliminating the need to transfer field notes by hand into base camp or office computer.

2. Project Unit 88–34. Geology of the Berens Lake–Deer Lake Area, Northwestern Ontario

D. Stone

Precambrian Geology Section, Ontario Geological Survey

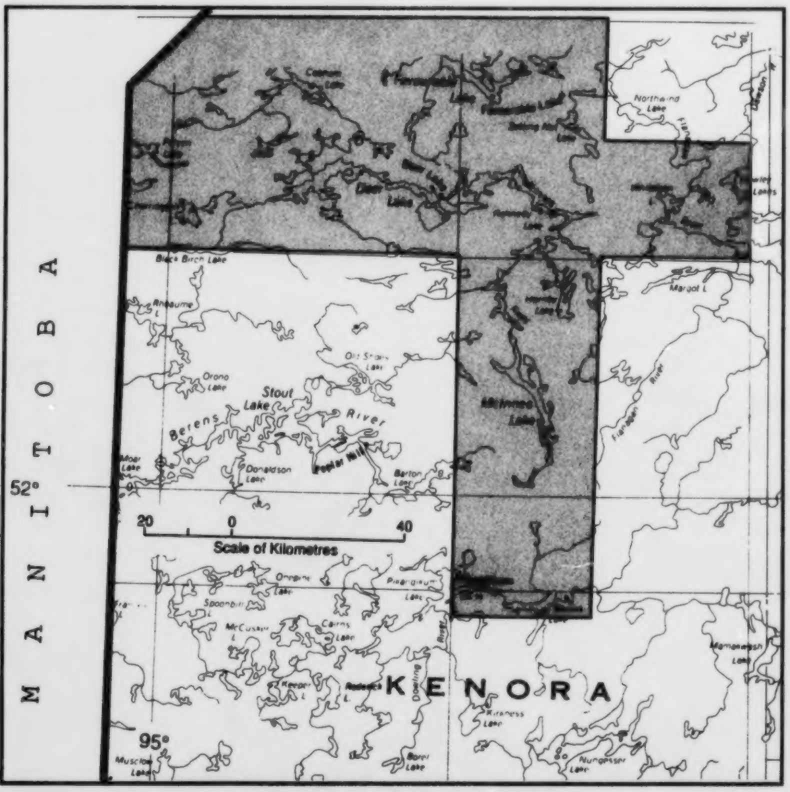
INTRODUCTION

Geological mapping of the Berens River Subprovince continued in 1991. Previous work in the Red Lake area (Stone 1989, 1990) was extended north through the central Berens River Subprovince and west to the Manitoba border. The area mapped by this year's field party (*see* Figure 1) includes the National Topographic System's (NTS) 1:50 000 scale quadrangle sheets 52N/13 (Berens Lake), 53C/4 (McInnes Lake), 53C/5 (Critchell Lake), 53C/12 (Kember Lake), 53D/9 (McIntosh Bay), 53D/10 (Cherrington Lake) and the Ontario part of 53D/11 (Kagipo Lake).

Objectives of the field work were to produce geological maps at a scale of 1:50 000 with emphasis on subdivision of felsic plutonic areas and definition of greenstone belts, including those at McInnes, Hornby and Cherrington lakes. The mapping from this and previous seasons covers a north-south geological section through the Berens River Subprovince and provides a base for mineral exploration and land-use planning.

MINERAL EXPLORATION

Mineral exploration is concentrated in greenstone belts at McInnes and Hornby lakes (*see* Figure 2) and at the northern margin of the Bear Head Lake Batholith (*see* Figure 3). In 1962, Phelps Dodge Corporation of Canada Limited drilled 12 holes totalling 952 m on 7 claim groups at McInnes Lake. The borehole logs (assessment files, Resident Geologist's office, Red Lake District, Red Lake) record disseminated pyrrhotite and pyrite in iron formation interlayered with metavolcanic and clastic metasedimentary rocks.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Stout Lake
Berens River
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Nungesser Lake

Figure 1. Location map, Berens Lake-Deer Lake area, scale 1:1 584 000.

Subsequently, in 1977, Cominco Limited performed an airborne magnetometer survey of the McInnes Lake greenstone belt followed by ground magnetic and horizontal loop electromagnetic surveys on 8 grids. Five boreholes totalling 625 m in length were drilled in metavolcanic rocks east of Power Bay, south of Middle Bay and on the west side of McInnes Lake (*see* Figure 2). Partial sections from 3 holes of the Cominco Limited drill program are archived in the Kenora Drill Core Library.

Placer Dome Incorporated recently completed ground magnetic and very low frequency electromagnetic surveys that defined a conductive zone of probable iron formation along the eastern shore of McInnes Lake in the Power Bay to Middle Bay area.

In 1968, Asbestos Corporation Exploration Limited conducted ground electromagnetic, magnetic and geological surveys, trenching, and drilled 6 boreholes, totalling 127 m, on a series of sulphide showings in felsic and mafic metavolcanic rocks east of Hornby Lake (*see* Figure 2). Mineralization was found to consist of pyrrhotite with minor chalcopyrite. Coin Lake Gold Mines Limited did airborne spectrometric, magnetometer and electromagnetic surveys over most of the Hornby Lake greenstone belt in 1970–1971. Cochenour Willans Gold Mines Limited trenched several uranium showings, in 1975, at the northern margin of the Hornby Lake greenstone belt east of Warwick Lake (*see* Figure 3).

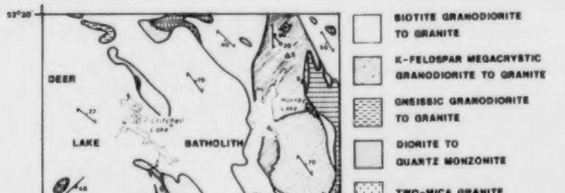
53°30'
53°15'
53°00'
52°45'
94°00
93°30'
DEER
LAKE
BATHOLITH
Critchell Lake
Power Bay
Middle Bay
Hornby Lake
Hampton Lake
Barton Lake
SPARLING
PLUTON
Sparling Lake
Pikangikum
River
BERENS
BIOTITE GRANODIORITE TO GRANITE
K-FELDSPAR MEGACRYSTIC GRANODIORITE TO GRANITE
GNEISSIC GRANODIORITE TO GRANITE
DIORITE TO QUARTZ MONZONITE
TWO-MICA GRANITE
BIOTITE TONALITE TO GRANODIORITE
HORNBLENDE TONALITE TO GRANODIORITE
GNEISSIC TONALITE TO GRANODIORITE
METAGABBRO, METAPERIDOTITE
METASEDIMENTARY ROCKS
INTERMEDIATE METAVOLCANIC ROCKS
MAFIC METAVOLCANIC ROCKS
GEOLOGICAL CONTACT
FOLIATION WITH DIP, WITHOUT DIP
GNEISSOSITY WITH DIP
MINERAL LINEATION WITH PLUNGE
SULPHIDE SHOWING
0
10 km

Figure 2. Geology of the Berens Lake, McInnes Lake and Critchell Lake areas.

Uranium exploration occurred from 1967 to 1968 at the northeastern margin of the Bear Head Lake Batholith (*see* Figure 3). Albatros Gold Mines Limited, Cam Mines Limited, Keevil Mining Group Limited and Summit Exploration Limited undertook airborne radiometric and spectrometric surveys over claim groups that covered the northeastern margin of the Bear Head Lake Batholith, the Bear Head Fault Zone and parts of the Favourable Lake greenstone belt. Trenching and approximately 1828 m of drilling was done on several claim groups mainly by Keevil Mining Group Limited and Summit Exploration Limited.

Uranium showings that consist of patches of uranophane on red granite occur in the central part of the Bear Head Lake Batholith, north of Deer Lake (*see* Figures 3 and 4). In 1977, Noranda Exploration Company did scintillometer surveys, geological mapping and trenching on these showings.

GENERAL GEOLOGY

The present field work area lies within the central and northern parts of the Ontario segment of the Berens River Subprovince. As defined by Card and Ciesielski (1986), the Berens River Subprovince is a large domain that extends east from Lake Winnipeg, in Manitoba, to Pickle Lake and is underlain by Archean felsic plutonic rocks and small greenstone belts of high metamorphic grade. Regional geology was previously studied by Ayres et al. (1973) and Ermanovics (1970) who separately produced maps at a scale of approximately 1:250 000 for the Ontario and Manitoba parts of the Berens River Subprovince, respectively. Ayres (1970, 1972) mapped the northeast part of the Kember Lake area as part of a detailed survey of the Favourable Lake greenstone belt. Cortis et al. (1988) described the geology of the McInnes Lake and Hornby Lake greenstone belts.

Intrusive Rocks

Felsic plutonic rocks underlie approximately 90% of the Berens Lake–Deer Lake area (*see* Figures 2, 3 and 4); their characteristics are summarized in Table 1. The main subdivisions are biotite hornblende tonalite to granodiorite and biotite tonalite to granodiorite of the sodic suite, and megacrystic granodiorite to granite and biotite granodiorite to granite of the potassic suite.

Rocks of the sodic suite are typically well foliated and occur as irregular to belt like units and as inclusions in younger rocks of the potassic suite. Units of biotite tonalite to granodiorite are elongated and occur throughout the area, attaining their greatest extent within and adjacent to the granitic Deer Lake Batholith (*see* Figures 2, 3 and 4). In contrast, biotite–hornblende tonalite to granodiorite is concentrated at Pikangikum Lake (*see* Figure 2) and near Cherrington Lake (*see* Figure 4). A common, northwest

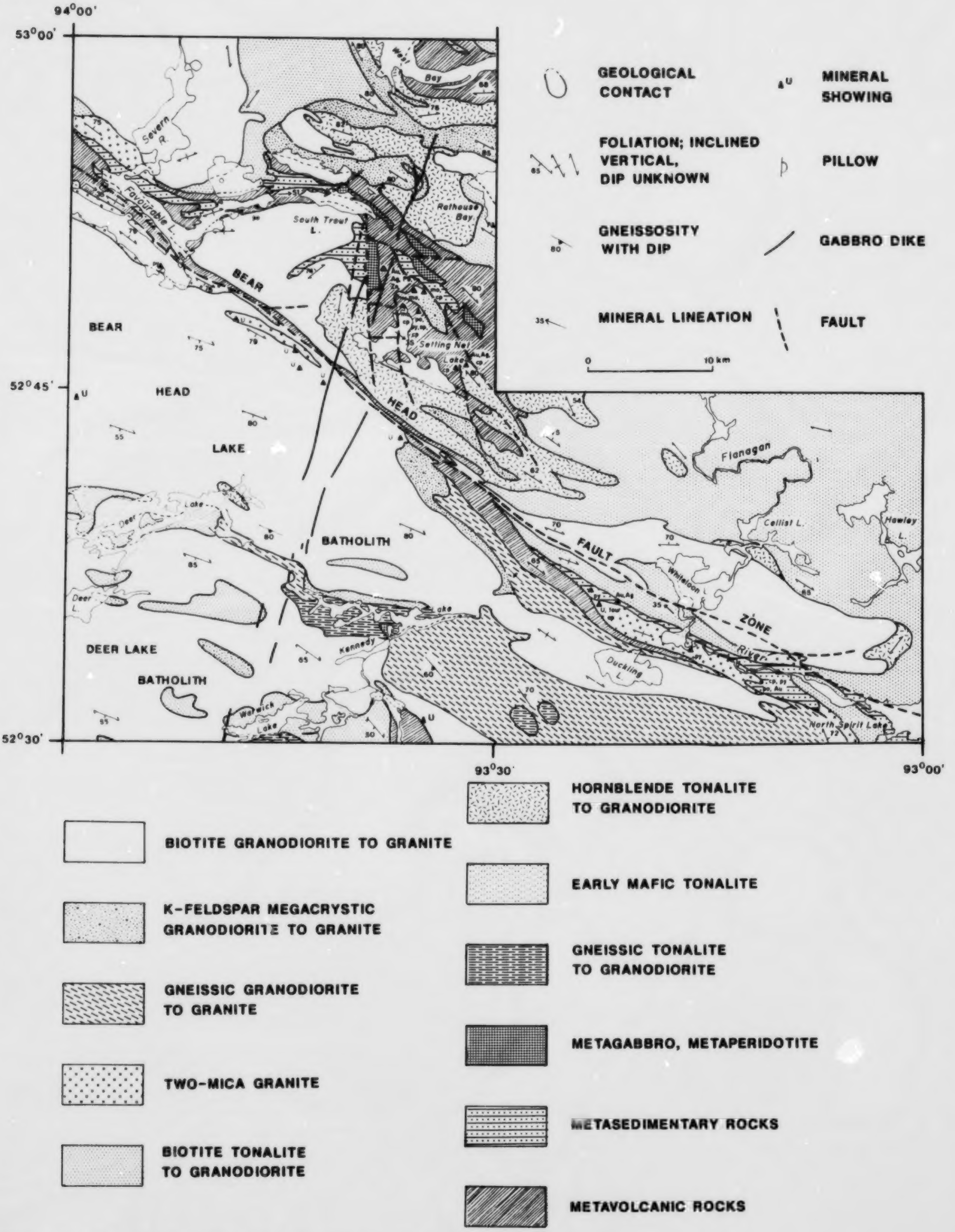
94°00'
53°00'
52°45'
52°30'
93°30'
93°00'
Severn R.
Favourable L.
West Bay
South Trout L.
Red Bay
Setting Net Lake
BEAR HEAD LAKE BATHOLITH
BEAR HEAD FAULT ZONE
DEER LAKE BATHOLITH
Deer Lake
Deer L.
Kennedy Lake
Warwick Lake
Flanagan
Cellist L.
Hawley L.
Whiteloon L.
Duckling L.
River
North Spirit Lake
GEOLOGICAL CONTACT
MINERAL SHOWING
FOLIATION; INCLINED VERTICAL, DIP UNKNOWN
PILLOW
GNEISSOSITY WITH DIP
GABBRO DIKE
MINERAL LINEATION
FAULT
0
10 km
BIOTITE GRANODIORITE TO GRANITE
K-FELDSPAR MEGACRYSTIC GRANODIORITE TO GRANITE
GNEISSIC GRANODIORITE TO GRANITE
TWO-MICA GRANITE
BIOTITE TONALITE TO GRANODIORITE
HORNBLENDE TONALITE TO GRANODIORITE
EARLY MAFIC TONALITE
GNEISSIC TONALITE TO GRANODIORITE
METAGABBRO, METAPERIDOTITE
METASEDIMENTARY ROCKS
METAVOLCANIC ROCKS

Figure 3. Geology of the Favourable Lake area (northwest quadrant), Kember Lake area (southwest quadrant) and Whiteloon Lake area (southeast quadrant). Geology of the Favourable Lake and Whiteloon Lake areas is compiled from Stone (1990).

trending structural fabric suggests that these hornblende bearing units may join west of the McInnes and Critchell Lake areas.

Potassium-feldspar-megacrystic granodiorite to granite occurs sporadically throughout the Berens Lake–Deer Lake area and is mineralogically and texturally gradational to biotite hornblende tonalite to granodiorite; units of these rocks tend to occur together.

Biotite granodiorite to granite is the most widespread felsic plutonic rock and occupies several large intrusions, such as the Bear Head Lake Batholith, the Deer Lake Batholith and the Sparling Pluton as well as smaller bodies (*see* Figures 4, 3 and 2). Although locally massive and equigranular, biotite granodiorite to granite typically has a weakly foliated to gneissic, inequigranular fabric and contains assimilated inclusions of tonalite.

Hornblende, biotite and pyroxene bearing, felsic intrusive rocks, compositionally variable from granite through quartz monzonite to diorite, occur east of McInnes Lake in the Frame Lake Pluton (Corfu and Ayres 1984). The dioritic to monzonitic border phases of the Frame Lake Pluton occur in the eastern part of the current field work area (*see* Figure 2).

Elongate units of hornblende biotite granodiorite to granite gneiss and units of tonalite to granodiorite gneiss occur throughout the Berens Lake–Deer Lake area. These units are concentrated in a southeast trending belt at Kennedy Lake (*see* Figure 3). Supracrustal inclusions occur within the gneisses. Supracrustal rocks in greenstone belts are intruded by metagabbro and metaperidotite. Small units of two mica granite also occur within and adjacent to greenstone belts. The youngest intrusive rocks are composed of unmetamorphosed gabbro and occur in south–southwest trending dikes (*see* Figure 3).

Supracrustal Rocks

Supracrustal rocks are found mainly in greenstone belts at McInnes Lake and Hornby Lake (*see* Figure 2), Setting Net Lake (*see* Figure 3) and Cherrington Lake (*see* Figure 4). Most are foliated, strained and metamorphosed to amphibolite facies.

McINNES LAKE GREENSTONE BELT

The McInnes Lake greenstone belt is elongate north to northwest trending over a distance of about 30 km and attains an average width of about 4 km (*see* Figure 2). It is composed mainly of volcanic breccia, tuff breccia and tuff of intermediate composition. Volcanic strata are subvertical, and outcrops have a streaky, pitted appearance due to weathering of stretched volcanic fragments. The present mapping shows that a narrow unit of intermediate metavolcanic rocks extends 25 km south from McInnes Lake to Berens Lake (*see* Figure 2).

Mafic metavolcanic rocks that originated as pillowed submarine lava flows occur mainly at the northern end of the McInnes Lake greenstone belt. At the southern end of Middle Bay, the mafic flows are completely silicified exhibiting aggregates of garnet and sillimanite.

Felsic pyroclastic rocks, composed mainly of subrounded breccia fragments, lie east of, and possibly on top of, the mafic metavolcanic unit at Power Bay. Wacke occurs and is intruded by two mica granite at the northern end of Power Bay. A thin unit of wacke and iron formation extend along part of the contact of mafic and intermediate volcanic rocks at the eastern shore of McInnes Lake.

HORNBY LAKE GREENSTONE BELT

The Hornby Lake greenstone belt is a bifurcated, northerly elongated enclave of supracrustal rocks that attains a maximum width of about 10 km (*see* Figures 2 and 3). Northern and western parts of the Hornby Lake greenstone belt are made up of pillowed and massive volcanic flows and conformable intrusions of mafic to ultramafic composition. These rock units show consistent northerly strike and intermediate to steep, easterly dip. Sulphide facies iron formation occurs within the volcanic rocks northeast of Hornby Lake.

Intermediate volcanic breccia is concentrated in a narrow (less than 400 m wide), north trending unit at the eastern side of the belt. Eastern parts of the belt and a narrow zone that extends to the south of Hampton Lake (*see* Figure 2) are

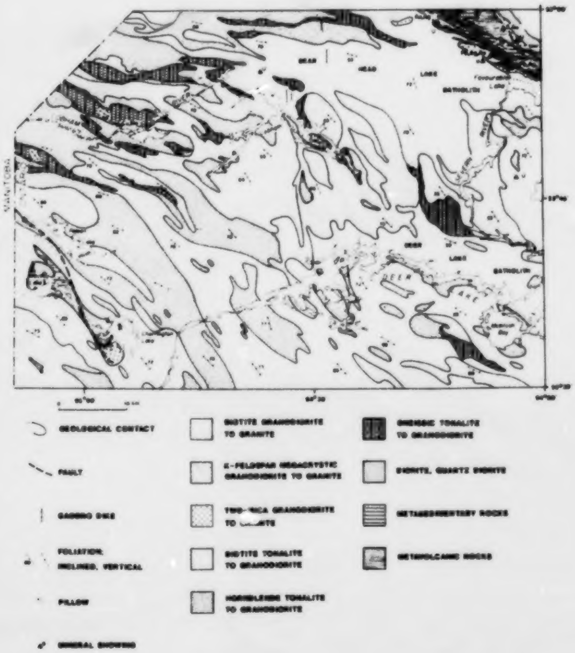
MANITOBA
BEAR
HEAD
LAKE
BATHOLITH
DEER
LAKE
BATHOLITH
GEOLOGICAL CONTACT
FAULT
GABBRO DIKE
FOLIATION: INCLINED, VERTICAL
PILLOW
MINERAL SHOWING
BIOTITE GRANODIORITE TO GRANITE
K-FELDSPAR MEGACRYSTIC GRANODIORITE TO GRANITE
TWO-MICA GRANODIORITE TO GRANITE
BIOTITE TONALITE TO GRANODIORITE
HORNBLENDE TONALITE TO GRANODIORITE
GNEISSIC TONALITE TO GRANODIORITE
SYENITE, QUARTZ SYENITE
METASEDIMENTARY ROCKS
METAVOLCANIC ROCKS

Figure 4. Geology of the McIntosh Bay area (southeast quadrant), Cherrington Lake area (southwest quadrant), Cobham Lake area (northwest quadrant) and Borland Lake area (northeast quadrant). Geology of the Cobham Lake and Borland Lake areas is compiled from Stone (1989).

Table 1. Characteristics of predominant felsic plutonic rocks in the Berens River Subprovince.

Rock Type (after Streckeisen 1976)	Colour	Grain Size	Fabric	Colour Index %	Form	Age Ma
Biotite granodiorite to granite	pink	variable, usually coarse inclusions	massive, has assimilated	<10	large batholiths	2720–2697
K-feldspar megacrystic biotite granodiorite to granite	pink	coarse	weakly foliated, megacrystic	5–15	irregular batholiths, inclusions	2717
Gneissic hornblende-biotite granodiorite to granite	white, pink	variable	layered	5–20	belts	–
Hornblende-biotite syenite, quartz monzonite, quartz monzodiorite, diorite	red, grey	variable	inequigranular, mafic clots	5–15	oval plutons	2696
Two-mica granodiorite to granite	white	coarse to pegmatitic	massive, protomylonitic	<10	elongate intrusions	–
Biotite tonalite to granodiorite	white, grey	medium to coarse megacrystic	foliated, gneissic, quartz or feldspar	5–15 inclusions	irregular to lobate bodies,	–
Biotite-hornblende tonalite to granodiorite	grey	coarse	foliated, feldspar megacrystic, mafic clots	10–30	irregular bodies, inclusions	2731

composed of metasedimentary and rare, mafic metavolcanic rocks. Most outcrops show migmatized wacke which is locally interbedded with quartz wacke and quartz arenite. Garnet and sillimanite are common metamorphic minerals.

FAVOURABLE LAKE GREENSTONE BELT

The Favourable Lake greenstone belt lies mainly north of the present field work area (*see* Figure 3) and extends more than 100 km west–northwesterly beyond the Manitoba border at the southern margin of the Sachigo Subprovince. Geochronologic and structural analyses (Ayres and Corfu 1991) have defined 5 structurally interleaved volcanic groups ranging from mafic and ultramafic flow sequences to intermediate and felsic pyroclastic rocks with intercalated clastic and chemical metasediments in the Setting Net–South Trout lakes area.

A narrow (less than 2 km wide) extension of this greenstone belt passes southeasterly, through the Kember Lake area (*see* Figure 3) along the Bear Head Fault Zone; it is composed of vertically dipping, mafic to intermediate volcanic rocks and minor clastic metasediments intruded by several varieties of granodiorite to granite. The supracrustal rocks are strongly foliated to gneissose and show amphibolite facies mineralogy.

CHERRINGTON LAKE GREENSTONE BELT

The Cherrington Lake greenstone belt extends 18 km in length in a northwesterly direction toward the Manitoba border (*see* Figure 4) and attains a maximum width of 5 km. Surrounded by biotite granite, the Cherrington Lake greenstone belt is composed almost entirely of pillowed, mafic volcanic flows with thin, ultramafic units. Intermediate to felsic volcanic rocks and metasediments are absent, except for minor ferruginous chert horizons.

The stratigraphic younging direction, derived from the shapes of large, weakly deformed pillows in the centre of the belt, is to the northeast. Diorite and granite intrude the northwestern part of the belt.

STRUCTURE

Structural trends, defined by foliations, gneissosity and lithologic contacts, follow broadly curved trajectories. In the south, from Berens Lake to McInnes Lake (*see* Figure 2), structural trends are mainly northward oriented, curving northwesterly from Critchell Lake through Deer Lake to Cherrington Lake (*see* Figures 2, 3 and 4). Foliations have variable, mainly subvertical dip in the south and intermediate southwesterly dip in the north.

Supracrustal rocks in greenstone belts have been transposed, metamorphosed and distorted. Northeast-younging pillowed flows occur at several localities in the Cherrington Lake greenstone belt. Cortis et al. (1988) interpreted the McInnes Lake greenstone belt as a composite of 3 volcanic sequences, possibly imbricated by thrust faults. East-younging, pillowed flows have been mapped at the northern end of the belt; however, the structural younging direction for other areas has not been established. Sedimentary strata in the eastern Hornby Lake greenstone belt face southeastward (Cortis et al. 1988).

Several mylonite zones have been mapped in the area. The Bear Head Fault Zone is marked by a 200 to 300 m wide zone of mylonite at the northwestern margin of the Bear Head Lake Batholith (*see* Figure 3). Limited structural analysis (Stone 1990) suggests a dextral, transcurrent displacement of unknown magnitude.

The Cherrington Fault Zone extends southeastward from Palsen Lake through Cherrington Lake and bisects the Cherrington Lake greenstone belt (*see* Figure 4). Ermanovics (1970) traced this fault zone 30 km northwest from the Manitoba border. The Cherrington Fault Zone is defined by a 200 to 300 m wide zone of mylonite in felsic plutonic rocks and broadens at its southeast terminus. Subhorizontal mineral lineations imply a transcurrent motion, although the amount and sense of displacement is unknown.

A broad area from western Deer Lake to Palsen Lake (*see* Figure 4) has been affected by late, brittle deformation. Many outcrops are cut by narrow, cataclastic faults and epidote filled fractures. Pseudotachylite has been observed in faults at two localities, and the drainage of the area is controlled by northwest trending lakes and valleys that may mark the surface trace of large fractures. These brittle fractures and faults, together with south–southwest-trending unmetamorphosed gabbro dikes in the Kember Lake area, suggest that parts of the region could have been brittlely deformed in the Paleoproterozoic (cf. Kamineni et al. 1990).

METAMORPHISM

Supracrustal rocks in all greenstone belts of the Berens Lake–Deer Lake area have mineral assemblages indicative of amphibolite facies metamorphism. Mafic metavolcanic rocks typically have assemblages of hornblende + plagioclase + quartz and hornblende + epidote + plagioclase + quartz. Garnet is common in volcanic rocks of the McInnes Lake greenstone belt.

Assemblages of garnet + biotite + sillimanite ± cordierite are noted in metasedimentary rocks of the Hornby and McInnes lakes greenstone belts. These belts do not show obvious patterns of metamorphic zonation typical of larger greenstone belts in the region (Ayres 1978).

Mafic tonalite gneisses north of Critchell Lake (*see* Figure 2) have a mineral assemblage of clinopyroxene + orthopyroxene + amphibole + feldspar + quartz indicative of granulite facies metamorphism.

DISCUSSION

Recent geological mapping shows the central and northern Berens River Subprovince to be underlain by several small greenstone belts of high metamorphic rank and by voluminous sodic and potassic intrusive rocks.

Belts of greenstone and gneisses, as well as some units of biotite tonalite to granodiorite, probably contain the oldest rocks in the area. The Cherrington and Hornby lakes greenstone belts comprise mafic and ultramafic volcanic sequences, typical of greenstone belts older than 2800 Ma in the northwestern part of the Superior Province (Thurston and Chivers 1990). Quartz arenite beds imply that metasedimentary rocks of the Hornby Lake greenstone belt were deposited on a stable, probably sialic, basement. Nearby units of biotite tonalite to granodiorite and tonalite to granodiorite gneiss are candidates for remnants of the basement complex.

The McInnes Lake greenstone belt is lithologically diverse, rich in intermediate volcanic fragmental rocks and, therefore, distinct from other greenstone belts of the Berens River Subprovince. Cortis et al. (1988) suggested that the McInnes Lake greenstone belt could be a composite of several episodes of volcanic activity, as has been demonstrated for the Favourable Lake greenstone belt (Ayres and Corfu 1991).

Although some tonalitic rocks can predate supracrustal rocks and, therefore, could have been emplaced prior to 2800 Ma, the available geochronologic data (summarized in Table 1) suggests that the bulk of the sodic and potassic intrusive suites were emplaced within a relatively short period of time, ranging from 2731 to 2696 Ma. This widespread plutonism profoundly changed the lithologic and structural character of the Berens River Subprovince. The biotite granites contain abundant, partly assimilated inclusions of older sodic intrusive rocks, and this implies some degree of recycling of earlier sialic crust to form granite batholiths.

Felsic plutonism was followed by ductile deformation in mylonite zones and, subsequently, by brittle deformation in the form of brittle fractures, faults and dikes.

ECONOMIC GEOLOGY

Mafic and ultramafic metavolcanic rocks provide a favourable environment for Cu-Ni mineralization and are situated in the northwestern Hornby Lake greenstone belt and in the Cherrington Lake greenstone belt.

Exploration for gold and base metals was directed at iron formation, more or less situated at the contact between mafic metavolcanic rocks and intermediate to felsic metavolcanic rocks in the McInnes Lake greenstone belt. These metals can also be associated with silicified mafic metavolcanic rocks occurring at the southern end of Middle Bay, of McInnes Lake (*see* Figure 2), and at the contact between mafic flows and intermediate volcanic fragmental and metasedimentary rocks situated east of Hornby Lake (*see* Figure 2).

Felsic plutonic rocks occurring at margins of the Cherrington Lake greenstone belt are mylonitized and fractured by the Cherrington Fault and locally contain disseminated sulphides; moreover, these deformed rocks can possibly host gold mineralization.

Uranium and rare metals (Li, Be) are associated with two mica granite, which occurs as small units in all greenstone belts and along the Bear Head Fault Zone (*see* Figure 3). For example, north of Duckling Lake (*see* Figure 3), pegmatitic dikes of two mica granite contain lithium bearing tourmaline, fluorapatite and possibly beryl and are locally coated by uranophane.

ACKNOWLEDGMENTS

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3. Project Unit 90–17. Geology of the Casummit Lake Area, District of Kenora (Patricia Portion)

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INTRODUCTION

Field work done in 1991 represents the final year of a two year project to complete the detailed mapping of the northern portion of the Birch Lake greenstone belt. The map area (Figure 1) is bounded approximately by latitudes 51°27'10"N and 51°34'30"N and longitudes 92°10'E and 92°34'E and covers approximately 270 km^2. The southern portion of this area was mapped in 1990. Field work carried out during 1991 extended this mapping to the north. The map area is located approximately 110 km northeast of the town of Red Lake. Access to the area is by float plane from Red Lake.

MINERAL EXPLORATION

The information on exploration activity summarized below is taken from previous reports on the area (Furse 1934; Horwood 1937) and from the Resident Geologist's files, Ontario Geological Survey, Red Lake.

Mineral exploration has been carried out intermittently over the last 60 years. Initial prospecting and exploration activity was sparked by the discovery of gold at Red Lake in 1926. This work led to the discovery of numerous gold occurrences. One significant deposit was discovered at this time (Argosy Mine) and ultimately produced 101 875 ounces of gold (average ore grade 0.37 ounces Au per ton) and 9788 ounces of silver.

Subsequent to the discovery of the South Bay copper-zinc deposit in 1968, the entire Birch–Uchi greenstone belt was explored for similar deposits. Very little follow-up work to airborne geophysical surveys was apparently carried out in the map area. Evaluation of disseminated molybdenum mineralization in the Mink Lake Stock (the principal occurrence lies just south of the map-area boundary) was carried out at this time.

Gold has been the focus of mineral exploration carried out during the last 15 years. Major exploration programs carried out during this time interval are summarized elsewhere (Beakhouse 1990). No mineral exploration activities are known to have been carried out within the map area during the past year.

GENERAL GEOLOGY

All of the bedrock in the area is inferred to be of Archean age. Many of the units mapped are continuous with those described for the areas to the south (Good 1988; Beakhouse

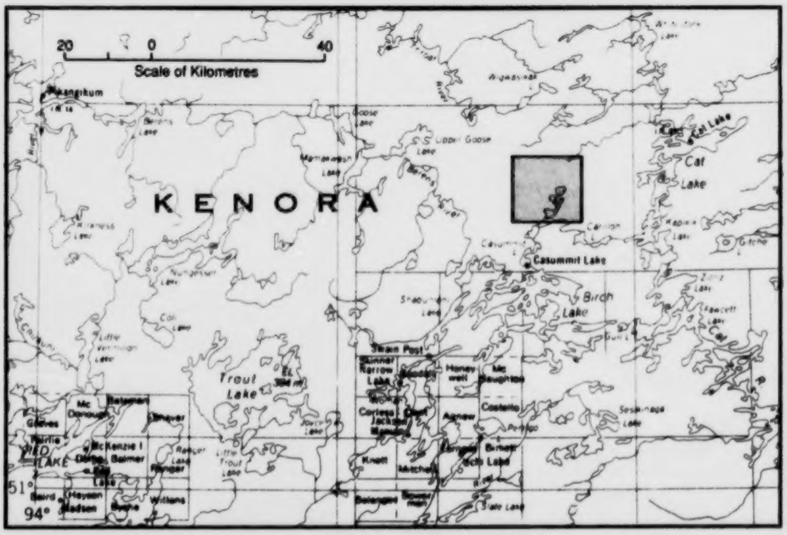

Figure 1. Location map of the Casummit Lake area, scale 1:1 584 000.

1989) but they are more deformed and less well exposed than they are in the Birch Lake area. Most of the map area is underlain by supracrustal rocks of the Birch–Uchi greenstone belt; the exceptions include those areas underlain by large external granitoid complexes which bound the greenstone belt and the Mink Lake stock (Figure 2).

Metavolcanic Rocks

Mafic metavolcanic rocks are a major component of this part of the greenstone belt. Massive and pillowed flows are both well represented; auto-brecciated flows are abundant locally, notably in the area east of the Argosy Mine. Medium-grained gabbroic rocks are commonly associated with the mafic metavolcanic rocks and may be either gabbro sills or thick or ponded flows.

Intermediate metavolcanic rocks are abundant in the south-central part of the map area (Beakhouse 1990). They are rare in that portion of the greenstone belt mapped during 1991. Several outcrops of highly deformed intermediate tuff and lapilli-tuff occur to the west of Brownstone Lake. Felsic metavolcanic rocks are restricted to the southern portion of the map area (Beakhouse 1990).

Metasedimentary Rocks

Metasedimentary rocks are a minor but widespread component of the southern part of the map area (*see* Figure 2; *see also* Beakhouse 1990) but do not occur in the area mapped during 1991. Examination of drill core from the southeastern portion of the map area indicates that a thin- to medium-bedded wacke/siltstone unit occurs along the eastern boundary of the greenstone belt southeast of Richardson Lake. There are no exposures of this unit but it is likely continuous with similar rocks occurring in the vicinity of Keigat Lake and the northeastern portion of Birch Lake (Good 1988).

Intrusive Rocks

Most of the intrusive rocks in the area mapped in 1991 are extensions of units described previously (Beakhouse 1990). Medium- to coarse-grained mafic igneous rocks are mainly associated with mafic metavolcanic rocks and are likely closely related (thick or ponded flows or related sills).

Medium- to coarse-grained felsic plutonic rocks intrude and bound the greenstone belt (Figure 2). All of these large plutonic complexes are dominated by medium-grained, microcline-megacrystic granodiorite intruded by subordinate

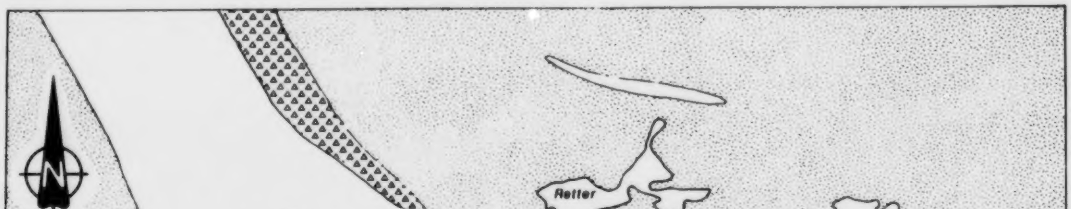
N
0
2 km
Retter Lake
Blondin Lake
Brownstone Lake
Richardson Lake
Argosy Mine
Casummit Lake
Joneston Lake
Mink Lake
MINK LAKE STOCK
Little
Shabumeni
(Birch Lake) McIntire Bay
Granitoid Rocks
Gabbro/Diorite
Clastic Metasedimentary Rocks
Felsic Metavolcanic Rocks
Intermediate Metavolcanic Rocks
Mafic Metavolcanic Rocks
Shear zone

Figure 2. Generalized geological map of the Casummit Lake area.

medium-grained, equigranular to coarsely pegmatitic leucogranite.

STRUCTURAL GEOLOGY

Much of the greenstone belt is characterized by the presence of a moderately well to intensely developed planar tectonic fabric that, where the two are observed together, is parallel, or nearly so, to bedding. Near the contacts with the external granitoid complexes, the fabric is oriented parallel to the boundaries of the greenstone belt. In the southern part of the map area, away from the margins of the belt, bedding and the subparallel planar fabric have a more variable but generally easterly trend. Some of the variation in the trend is a consequence of gentle to open folding about axes plunging steeply to the north. A fracture cleavage or penetrative planar fabric locally cuts the early bedding parallel fabric and is approximately parallel to the axial planes of the later folds.

ECONOMIC GEOLOGY

The map area has the potential for the discovery of additional gold deposits. Little evidence was encountered during the course of this investigation for conditions favourable for the formation of volcanogenic massive sulphide deposits although the possibility of finding such deposits cannot be completely discounted. The poorly exposed felsic unit south of Casummit Lake may be a porphyry analogous to that associated with the South Bay copper-zinc deposit. The Mink Lake stock may host additional disseminated molybdenum mineralization which, based on the known such occurrence just south of the map area, may have associated gold mineralization (Durocher 1981).

All of the greenstone belt has potential for the discovery of additional gold deposits; but, on the basis of the distribution of structures which host significant alteration, quartz-carbonate veins and disseminated sulphide mineralization as well as known occurrences, the general area of the contact between the dominantly mafic northern portion of the greenstone belt and the more heterolithic southern portion of the greenstone belt would appear to be most favourable. Within this area gold mineralization is hosted within structures (sheared zones and vein systems) provisionally interpreted to be related to the late infolding of the greenstone belt.

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4. Project Unit 91–04. Geology of the Dixie Lake Area

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INTRODUCTION

A 1-month reconnaissance evaluation of the Dixie Lake area was undertaken in August to develop familiarity with the geology and logistics of undertaking a proposed 2-year mapping project at scales of 1:15 840 and 1:50 000.

LOCATION

The Dixie Lake area is centred about 23 km south-southeast of Red Lake. The area, which encompasses 700 km^2, is bounded by latitudes 50°45'N and 50°56'N and by longitudes 93°30'W and 94°00'W (Figure 1). Highway 105, which connects Red Lake with Vermilion Bay on the Trans-Canada Highway (Highway 17) to the south, traverses the northeastern part of the map area. Gullrock Lake, part of the Red Lake system, and Pakwash Lake, part of the English River system, lie partly in the northeastern and southeastern parts of the map area, respectively.

The eastern third of the area is characterized by extensive Quaternary glacial deposits, commonly on the order of 5 to 50 m thick. The western half of the area is characterized by well-exposed knolls or outcrop areas separated by sizeable areas of glacial cover. A system of logging roads provides access to the central and northeastern parts of the map area. A large forest fire in 1980 ravaged much of the western and central parts of the area. Moderate to extensive wind damage to the forest occurred in the southern third, or unburned parts, of the map area this summer. Access to the western third and southeastern part of the map area is poor.

GENERAL GEOLOGY

Previously the map area received sparse detailed mapping because of thick glacial cover and lack of access. Presently logging roads have improved access. Detailed mapping (1:15 840) of the area bounding the eastern side of the map area, centred on the Griffith iron mine, was released by Shklanka (1970). Reconnaissance mapping of the general area was undertaken in 1974 (Breaks et al. 1975), followed by a compilation map (Breaks et al. 1978) and then by further compilation emphasizing regional stratigraphy (Thurston and Paktunc 1985). Some of the general information provided below comes from Breaks et al. (1975). Detailed observations are from this season's investigation.

Supracrustal Rocks

About 30% of the map area is underlaid by supracrustal rocks; the remaining 70% is various types of granitoid rocks (*see* Figure 2). The supracrustal rocks represent the contiguous and dismembered southwestern end of the Birch

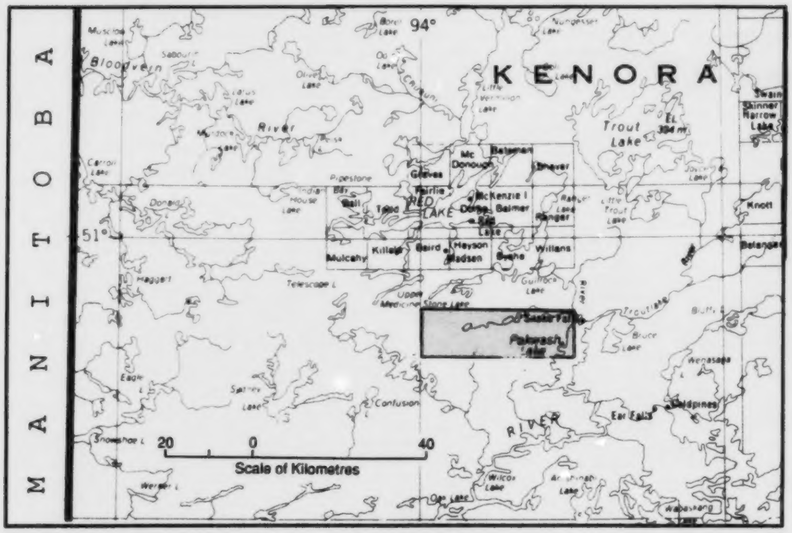

Figure 1. Location map, Dixie Lake area, scale 1:1 584 000.

Lake–Uchi Lake greenstone belt. As such, the Dixie Lake area supracrustal rocks are spatially separate from the 2.7 Ga southern fringe of the Red Lake greenstone belt assemblages with the exception of a small "protrusion" of supracrustal rocks into the area along Highway 105 at the north boundary of the area (*see* Figure 2). An apparently contiguous, narrow section of supracrustal rocks extends across the north part of the area.

The most extensive area of supracrustal rock lies in poorly exposed terrain in the east-central part of the map area. Exposures of the greenstone assemblage indicate that the rocks comprise the following:

1 "massive" and pillowed, mafic and mafic to intermediate volcanic flows;

2. intermediate and/or felsic to intermediate, feldspar- and quartz-feldspar-phyric volcanic deposits, many of which are fragmental units;

3. feldspathic arenite and feldspathic siltstone, possibly representing reworked volcanic-derived material laid down, in part at least, as turbidite deposits;

4. polymictic conglomerate containing a wide variety of metavolcanic and metasedimentary rocks as well as granitoid clasts;

5. a variety of banded iron formation consisting of magnetite layers interlayered with various combinations of silicate-rich, feldspar-rich, ferromagnesian-mineral-rich, and/or wacke-rich material; and

6. varieties of greywacke and dark grey siltstone.

Fragments of banded iron formation were locally noted in the polymictic conglomerate and some feldspathic arenite units.

Although strong to intense deformation characterizes the bulk of the extensive supracrustal section, rocks within the central part of the section are locally moderately deformed. Primary layering and top indications were rarely determinable. Exposed units displayed considerable flattening and layer-parallel to subparallel faulting as indicated by discordant layering and ultracataclasite.

Granitoid Rocks

The intermediate to felsic granitoid rocks are as follows:

1. The northern part of the area is separated from the Red Lake greenstone assemblages by weakly foliated, equigranular granite to quartz monzonite of the Gullrock Lake Batholith.

2. The west-central part is underlaid by metamorphosed, weakly to moderately foliated, locally gneissic tonalite and granodiorite of the Longlegged Lake Dome.

3. The southeastern part is underlaid by metamorphosed, weakly foliated tonalite which is separated from the Longlegged Lake Dome by a body of metamorphosed, foliated quartz diorite.

Virtually all of the granitoid bodies contain local to extensive areas of very large to small supracrustal xenoliths, particularly within 1 to 2 km of contacts with the supracrustal rocks. The xenoliths consist of amphibolite, amphibolitic gneiss and, in some cases, intermediate to felsic metavolcanic rocks and clastic metasedimentary rocks which display various stages of gneissic development. Locally, enclaves and schlieren of supracrustal rocks are present in various amounts. Pegmatite and/or aplite dikes are almost ubiquitous in the Gullrock Lake Batholith (within the map area) and at least part of the Longlegged Lake Dome. In some cases, feldspar crystals up to 12 cm long are present in the pegmatite dikes.

Complex, multiple-age relationships between granitoid rocks exist along the marginal zones with supracrustal rocks. This complexity and the large degree of stoping or incipient digestion of the supracrustal rocks in these zones preclude, in areas of small outcrops, a clear delineation of the contacts of the contiguous sections of supracrustal rocks.

STRUCTURAL GEOLOGY

All of the rocks underlying the Dixie Lake area show some degree of penetrative planar fabric development with the exception of some of the Gullrock Lake Batholith granite/quartz monzonite. Superposed on these fabrics, at least in part, are planar fabrics which are the result of shearing.

Supracrustal rocks of the Red Lake belt exposed on Highway 105 near the north boundary of the map area display a layer-parallel planar fabric (S_0/S_1) which is isoclinally folded about an S_2 fabric. These features have been overprinted by a northeast-striking crenulation fabric (S_3) that produced F_3 folds commonly having Z-shaped asymmetry. This crenulation fabric was noted in several parts of the map area in both supracrustal and granitoid rocks.

Sydney Lake Fault System

The Sydney Lake Fault System (Breaks et al. 1975, 1978; Stone 1981) lies to the south of the map area and separates the Uchi Subprovince from the Northern Supracrustal Domain of the English River Subprovince. It is a predominantly strike-slip zone of dextral shearing in which mylonitic, cataclastic and pseudotachylitic rocks are found (Stone 1981). An east- to northeast-striking branch of this system lies just outside the southern boundary of the map area. An east-northeast-striking branch extends to the east-central boundary of the map area in the vicinity of Snake Falls (Breaks et al. 1978).

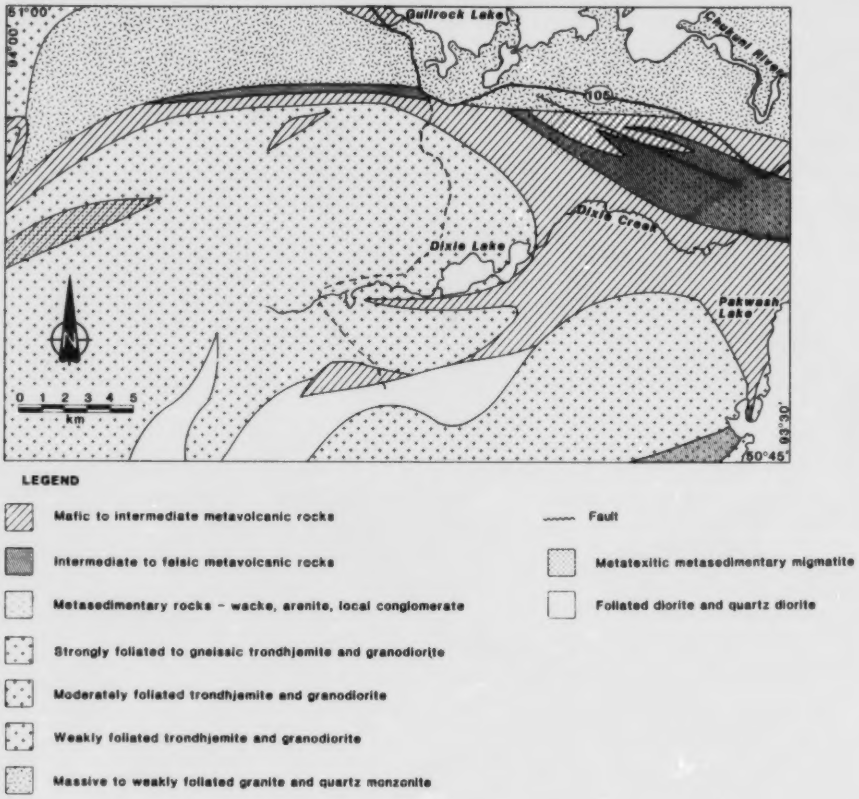
51°00'
94°00'
Gullrock Lake
Chukuni River
105
Dixie Creek
Dixie Lake
Pakwash Lake
N
0 1 2 3 4 5
km
93°30'
50°45'
LEGEND
▨ Mafic to intermediate metavolcanic rocks
■ Intermediate to felsic metavolcanic rocks
░ Metasedimentary rocks - wacke, arenite, local conglomerate
⁘ Strongly foliated to gneissic trondhjemite and granodiorite
⁘ Moderately foliated trondhjemite and granodiorite
⁘ Weakly foliated trondhjemite and granodiorite
░ Massive to weakly foliated granite and quartz monzonite
Fault
░ Metatexitic metasedimentary migmatite
☐ Foliated diorite and quartz diorite

Figure 2. General geology of the Dixie Lake area (modified after Breaks et al. 1978).

Zone of Intense Strain

Although no evidence of the east-northeast-striking branch was observed during this field season, all three types of sheared rocks listed above were observed in granitoid and supracrustal rocks within and south of the Gullrock Lake Batholith. Here, a dextral-predominant shear zone, striking at 120°, was traced in the Gullrock Lake Batholith south of Highway 105. Associated with this zone are quartz veins and/or silicification. A spatially and likely genetically associated deformation zone, at least 1 km wide, developed in supracrustal rocks immediately to the south. In this zone mafic, intermediate and felsic flows and pyroclastic deposits, clastic and chemical metasedimentary rocks and granitoid rocks are mylonitized. Cataclastic breccias and pseudotachylitic rocks are also present. Spatially associated shear zones have the following characteristics: dextral sense at 140°; and sinistral sense at 20°, 45° and 75° (strike precision ±5°). Medium- to small-scale Z-shaped folds, crenulation folds and conjugate kink folds (F_4) are interpreted to have resulted from progressive shearing.

The overall degree and style of deformation has produced considerably deformed, transposed and dislocated supracrustal rocks in which primary features and stratigraphic continuity largely have been destroyed. Hence, in general terms, mapping of the supracrustal rocks can only delineate zones in which the supracrustal rock predominates over granitoid rock. The extent of this deformation zone was not delineated.

ECONOMIC GEOLOGY

Exploration activity in the Dixie Lake area is currently being undertaken on property held by Mutual Resources Limited where the Dixie Lake gold occurrence includes a zone totalling 420 000 tons at an average grade of 0.13 ounces Au per ton (George Cross Newsletter, August 15, 1990) in mafic metavolcanic and clastic metasedimentary rocks (Atkinson et al. 1990).

During the field season, altered pyritized rocks were noted along Highway 105 south of the north boundary of the map area. The rock, which may be extensively altered, contains 5 to 10% pyrite as disseminated grains and grains along cleavage planes and appears to contain relict quartz and feldspar phenocrysts. Just to the north of this unit, exposed on Highway 105, is an altered unit presently consisting of biotite-feldspar schist. This schist contains numerous dark red, euhedral garnet crystals (up to 10%) and tentatively identified cordierite and sillimanite. Locally, white "halos", possibly consisting of quartz and/or feldspar in which there is no biotite, surround clusters of anhedral garnet crystals. The protolith of this rock is unclear, as is any association of the unit with a shear zone.

Several small trenches were noted during the course of mapping this season. In all cases, considerable magnetite with various amounts of pyrite and pyrrhotite were found in mafic rocks (metavolcanic?) and/or clastic metasedimentary rocks. The magnetite did not appear to be layered in any of the trenches.

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5. Project Unit 91–06. Geology and Mineral Potential of the Wild Potato Lake Area, District of Rainy River

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INTRODUCTION

Located 61 km east of Fort Frances on Trans-Canada Highway 11, the town of Mine Centre is 9 km west of the western boundary of the map area (Figure 1). The project area encompasses 200 km^2 and is bounded by lat. 48°39'N and 48°49'N and by long. 92°15'W and 92°30'W.

This summary of field work is a preliminary report of the results of 12 weeks of field mapping, the objectives of which were to: 1) produce a geological map of a previously unmapped area of mineral potential, 2) locate potential exploration targets and 3) study the style of progressive deformation along a subprovince boundary.

MINERAL EXPLORATION

Information on exploration work was obtained from assessment work on file in the office of the Resident Geologist (districts of Kenora and Thunder Bay), Ontario Ministry of Northern Development and Mines (Thunder Bay) and from the Mines Library and Assessment Files Research Office, Ontario Geological Survey (Toronto).

In 1882, the Canadian Pacific Railway was completed as far west as Lake of the Woods (District of Kenora) and afforded easy access to the Rainy Lake and the Seine River system. A gold rush in northern Minnesota at that time lead to a similar rush in the previously inaccessible Mine Centre area. Gold was first discovered near Mine Centre in 1893 and, by 1904, many shafts had been sunk and several small mines developed, but only the Olive, Golden Star and Foley mines produced any gold. The early focus of exploration in the Mine Centre area was for gold, but in the 1950's interest in base metals sparked renewed interest in the region. With the release of an airborne geophysical survey funded by the Ontario Geological Survey (OGS 1980) gold again became the focus of exploration, an interest which has remained high to the present day.

GENERAL GEOLOGY

The map area contains the boundary of the Wabigoon and Quetico subprovinces and, in particular, a wedge-shaped terrane which to the north rests unconformably upon metavolcanic rocks, presumably of the Wabigoon Subprovince, and to the south is bordered by the Seine River fault zone. The

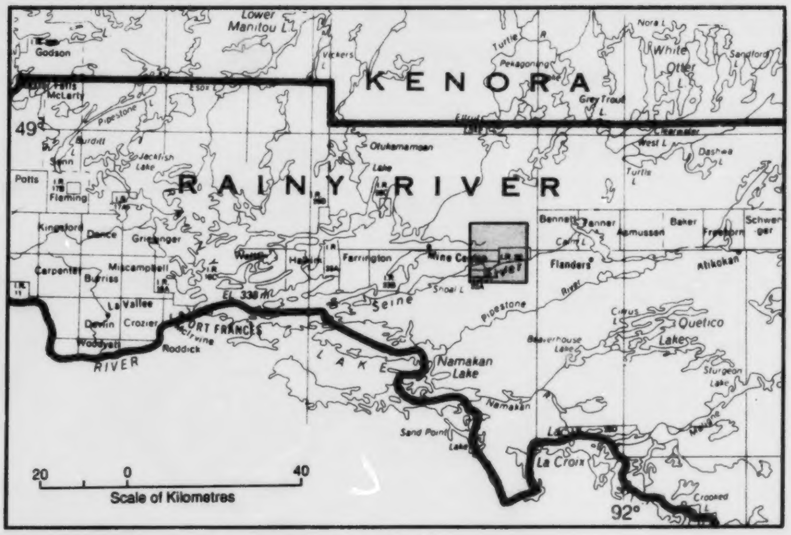

Figure 1. Location map of study area, scale 1:1 584 000.

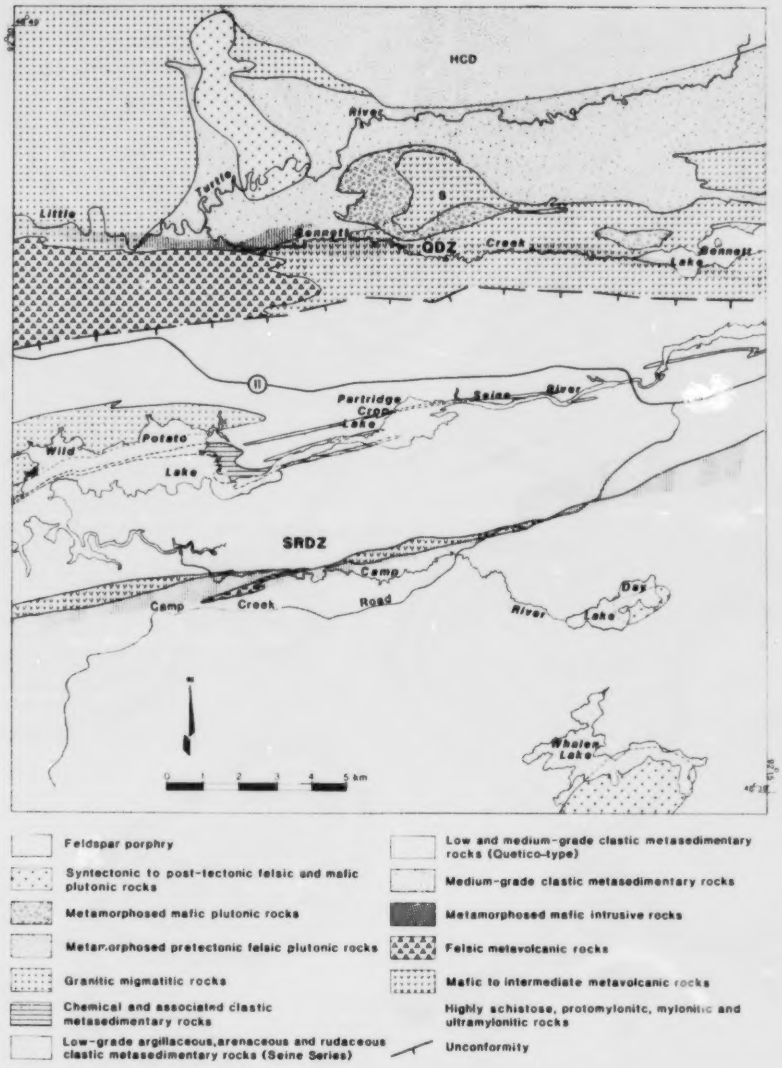
HCD
River
Turtle
Little
Bennett
QDZ
Creek
Bennett
Lake
S
11
Partridge
Crop
Lake
Seine
River
Potato
Wild
Lake
SRDZ
Camp
Creek
Camp
Road
River
Dew
Lake
Whalen
Lake
N
0 1 2 3 4 5 km
Feldspar porphry
Syntectonic to post-tectonic felsic and mafic plutonic rocks
Metamorphosed mafic plutonic rocks
Metamorphosed pretectonic felsic plutonic rocks
Granitic migmatitic rocks
Chemical and associated clastic metasedimentary rocks
Low-grade argillaceous, arenaceous and rudaceous clastic metasedimentary rocks (Seine Series)
Low and medium-grade clastic metasedimentary rocks (Quetico-type)
Medium-grade clastic metasedimentary rocks
Metamorphosed mafic intrusive rocks
Felsic metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Highly schistose, protomylonitc, mylonitic and ultramylonitic rocks
Unconformity

Figure 2. Simplified geological map of the project area. QDZ, Quetico deformation zone; SRDZ, Seine River deformation zone; HCD, Hillyer Creek Dome; S, gossan.

map area is conveniently separated into five litho-tectonic "domains" which are commonly shear-zone bounded (Figure 2). Descriptions of these domains are given below.

Domain 1: Plutonic-Supracrustal Terrane North of the Quetico Deformation Zone

In the map area, the Quetico Fault, herein renamed the Quetico deformation zone (QDZ) runs along Bennett Creek (Figure 2). The QDZ separates a low-grade sliver of metavolcanic rocks, presumably belonging to the Wabigoon Subprovince, from a northern terrane consisting of higher-grade plutonic-supracrustal rocks of the Wabigoon Subprovince. Supracrustal rocks to the north of the QDZ are mainly biotite-garnet schists and are similar in many respects to the higher-grade metasedimentary rocks of the Quetico Subprovince. Other than bedding, no unequivocal primary sedimentary structures were found in these mudstones and feldspathic wackes. Metavolcanic rocks are volumetrically less abundant than the metasedimentary rocks and are commonly metamorphosed to amphibolite facies.

The Hillyer Creek Dome (Figure 2) is composed of well-foliated medium-grained (2 to 5 mm) tonalites and rarely granodiorites. A contact metamorphic aureole up to 300 m wide borders the southern side of the dome. In the aureole, garnet-hornblende rich rocks predominate and are interpreted to be of sedimentary origin. The rocks are composed of 40% to 60% garnet, locally golf-ball size, which may coallesce to form metre-long pods on horizontal outcrop surfaces. Outcrops largely devoid of other intrusive phases are typical of the eastern portion of the Hillyer Creek Dome, but in the west the body has been intruded by late- to post-tectonic granitic rocks which effectively obscure the western boundary of the dome and its contact with granitic migmatites.

Domain 2: Metavolcanic Rocks between the QDZ and Seine "Series"

South of the QDZ, metavolcanic rocks have been metamorphosed to only greenschist facies. Quartz porphyritic felsic flows predominate in the western portion of the domain, whereas in the east the rocks are mainly mafic to intermediate flows and tuffaceous rocks. This outcrop distribution is suggestive of a regional fold, although no top directions could be determined anywhere in the domain. The felsic flows have been carbonatized and sericitized and contain abundant discordant quartz veins.

Domain 3: Seine "Series"

A wedge-shaped terrane of metasedimentary rocks rests unconformably upon a narrow belt of metavolcanic rocks in the north and to the south is bordered by the Seine River deformation zone. This wedge-shaped terrane consists of metasedimentary rocks historically known as the Seine "Series" (Lawson 1913) which are thought to have been deposited in a shallow pull-apart basin between major wrench faults (Poulsen 1984). Four facies are present in the Seine "Series" rocks, namely, conglomerate, pebbly sandstone, sandstone, and siltstone (Wood 1977).

The conglomerates are polymictic and typically clast supported. They are composed mainly of volcanic detritus in which the volume of plutonic rock clasts rarely exceeds 20% of the total clast population. The plutonic rock clasts are commonly unfoliated, an observation which poses important questions as to the source area of such clasts or the age of sedimentation of the conglomerates relative to regional deformation. The matrix to the clasts is a medium- to coarse-grained sand composed of feldspar and quartz grains. However, the matrix is not always discernable because of poor rock exposures and high strain levels within many outcrops.

Thinly to very thickly bedded sandstones occur interbedded with the conglomerates. Bedding within the sandstones is discontinuous on the scale of a few metres to tens of metres. Zones of conglomerate may be interleaved with the sandstones and pebble- to cobble-sized clasts may be found near the medians of many sandstone beds. Compositionally, the sandstones are arkoses and wackes in which quartz content rarely exceeds 50% and is commonly 20% to 40%. Planar cross-bedding and trough cross-bedding are common primary features of the sandstones, but the highly schistose nature of these rocks makes many top determinations uncertain. Most of the sandstones contain small amounts of felsic volcanic clasts and hence are mainly lithic arkoses.

Linear bands of feldspar porphyry have minimum thicknesses which exceed 20 m and are present throughout the Seine "Series" rocks. Subhedral to euhedral feldspar crystals (2 to 8 mm) account for 40% to 60% of the rock and are unfractured in weakly strained portions of the rock. The linear outcrop pattern suggests that the feldspar porphyries are intrusive sheets. A thin (less than 1 m) sheet of feldspar porphyry, which resembles the larger feldspar porphyry bodies, locally crosscuts layering within iron formation. However, clasts of feldspar porphyry are conspicuous in many outcrops of polymictic conglomerate (Photo 1), an observation which suggests several ages of feldspar porphyry.

Domain 4: Metavolcanic Rocks in the Seine River Deformation Zone

A sliver of metavolcanic rocks occurs within the Seine River deformation zone (SRDZ) and lies between rocks of the Seine "Series" and rocks of the Quetico Subprovince. The sliver consists of mafic to intermediate volcanic rocks as well as porphyritic felsic volcanic rocks.

One lobe of felsic to intermediate volcanic flows occurs within the SRDZ and is apparently enclosed within graded wackes of the Quetico Subprovince. The flows may contain feldspar and/or quartz phenocrysts which are set in a fine-grained to aphanitic groundmass. Lenticular zones of interflow tuffs (?) separate some of the flows. Although entire flow units were not seen, exposed thickness of the flows

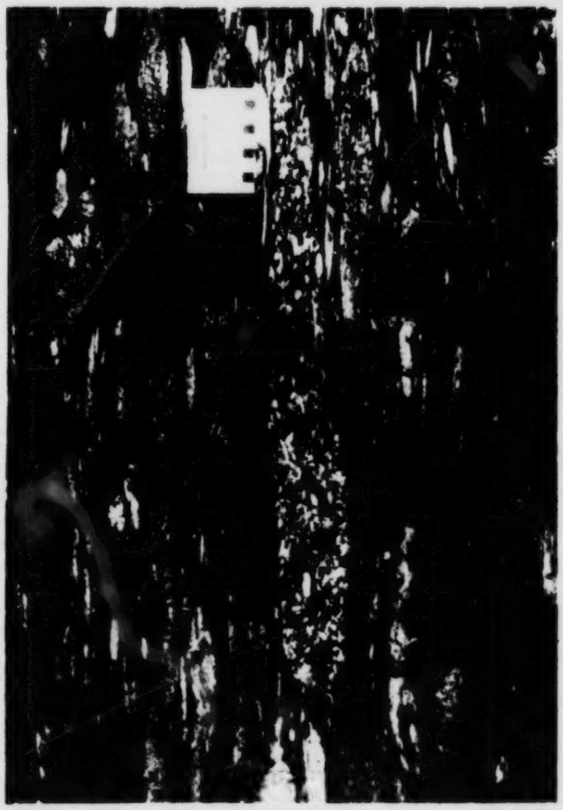

Photo 1. Clast of feldspar porphyry (centre) within Seine "Series" conglomerate.

exceeds 20 m. Contacts of this lobate zone of volcanic flows with the graded metasedimentary rocks are rare. Any exposed contacts are highly sheared. Bedding within the adjacent wacke-mudstone assemblage is discontinuous on the scale of metres and subvertical contractional mesofaults displace the layering and the flows. This observation suggests that the lobe as a whole may have been sheared into the sedimentary assemblage. The occurrence of other volcanic-looking material elsewhere in the Quetico Subprovince is not so simply explained.

Domain 5: Quetico Subprovince

South of the Seine River deformation zone (SRDZ), a wacke-mudstone assemblage forms the bulk of the Quetico Subprovince. Near the southern margin of the deformation zone, the feldspathic wackes are graded and are interpreted to be turbidites that were deposited in deep water below storm wave base (Walker 1981). A 2 to 3 m banded chert horizon has a strike length of nearly 400 m and occurs entirely within the graded wackes near the southern margin of the SRDZ. Here, the metasedimentary assemblage is predominantly northward-younging and has been metamorphosed to greenschist facies. Southwards from the SRDZ the metamorphic grade increases, most primary features are obliterated and dioritic and granitic mobilizate attest to local anatexis of some of the biotite-garnet-andalusite schists of the Quetico Subprovince. Compositional banding may be relic bedding or else the layering may be due to tectono-metamorphic differentiation.

Two small syn- to post-tectonic potassic stocks intrude the metasedimentary rocks (Figure 2). Each is highly heterogeneous and consists of diorite, monzonite and syenite. Both the Whalen Lake and Day Lake stocks carry abundant xenoliths of metasedimentary rocks, an observation which implies that the stocks have been unroofed near their upper contact surfaces.

STRUCTURAL GEOLOGY

Throughout the map area bedding and schistosity strike east to east-northeastward and in most outcrops are nearly parallel. There is ample evidence of bedding transposition.

The Quetico and Seine River deformation zones are major zones of ductile shear, are, in places, at least 1 km thick, and contain protomylonites, mylonites and ultramylonites. Numerous smaller deformation zones are present in the map area and contain protomylonitic rocks, cataclastites and pseudotachylites, similar to that of the major zones of deformation. In some deformation zones, polymictic conglomerates have a laminated appearance with any remaining clasts having aspect ratios exceeding 100 in horizontal section (Photo 2). At more advanced stages of deformation the conglomerates have an ultramylonitic texture in which few clasts can be observed within a finely comminuted matrix. At this advanced stage of deformation, other rocks interpreted by the author to be sandstones have a glassy-looking matrix.

Photo 2. Highly deformed Seine "Series" conglomerate within the Seine River deformation zone. Felsic volcanic fragments are readily visible in a green matrix. Hammer is 41 cm long, hoe-end points to south. Note small band of lithic arkose to the south of the hammer.

Within these ductile shear zones mineral elongation lineations rake shallowly (eastward in the QDZ and westward in the SRDZ) within east-northeastward-striking subvertical foliation surfaces. Discrete subvertical planar surfaces clockwise of the mineral foliation are analogous to C-planes (Berthé et al 1979) and attest to a strong component of dextral transcurrent shear. In some rocks of the Quetico deformation zone and in many rocks of the Seine River deformation zone C-S and C'-planes are apparent and together with subhorizontal mineral lineations imply a large component of dextral transcurrent shear.

Away from the deformation zones and well exposed in outcrops along Highway 11, mineral elongation lineations rake steeply, either east or west, within east-northeastward-striking schistosity surfaces. Poor three-dimensional exposures elsewhere in the map area preclude any estimate of the volume of rock with such steeply raking elongation lineations. Apparently, steeply raking lineations were progressively reoriented during later transcurrent shear and have assumed shallow rakes within many linear deformation zones. Moreover, on many horizontal outcrop surfaces in conglomerates of the Seine "Series", the asymmetry of pressure shadows and clast long axes with respect to foliation, in conjunction with subhorizontal quartz-fibre infillings in broken clasts, attest to a late increment of horizontal dextral shear superimposed on a previously inverted supracrustal succession. This deformation scenario is akin to dextral transpression.

MINERALIZATION

Ductile shear zones should be considered the major exploration target in the map area. Five of seven abandoned mine shafts occur within mylonites of the Quetico or Seine River deformation zones of the present area and the Olive Mine, a past-producer, is situated just west of the map area in mylonitic felsic to intermediate volcanic rocks of the QDZ. There exists the possibility of low-grade, large-tonnage-potential gold deposits associated with these and other shear zones. As at the Olive Mine, syntectonic quartz veins within mylonitized felsic volcanic rocks of the QDZ in the present area may yield high-grade, low-tonnage gold deposits.

In the map area, quartz veins range in width from less than one centimetre to more than several metres. Commonly the veins are lenticular and accessory minerals include ankerite, sphalerite, chalcopyrite and rarely arsenopyrite. The geometry of the veins suggests that many are syntectonic.

In the Mine Centre area, gold is reported (Assessment Files Research Office, Ontario Geological Survey, Toronto) to occur within recrystallized pyritic chert as well as in crosscutting quartz stringers. Several chert horizons were noted in the course of mapping, the largest of which occurs just north of Camp Creek Road (Figure 2).

A number of gossans occurs in supracrustal rocks of Domain 1. One such gossan (Polygon Lake occurrence) consists of abundant magnetite and pyrite with small amounts of chalocpyrite and occurs within amphibolitized mafic volcanic rocks (S on Figure 2). The pyrite may be nodular and no banding was noted within the gossan zone.

CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS

1 The SRDZ and QDZ are major structural breaks along which dextral transcurrent shear was the main mechanism of deformation.

2 Protomylonites, mylonites and ultramylonites are the main shear zone rocks and are indicative of large amounts of ductile shear. Cataclastites and pseudotachylites crosscut the mylonitic foliation and attest to repeated movement in the fault zones.

3 Kinematic indicators exposed on horizontal outcrop surfaces throughout the Seine "Series" conglomerates suggest a late increment of horizontal dextral shear.

4 Relic bedding is commonly discontinuous and subparallel to schistosity throughout much of the map area.

5 Plutonic rock clasts within the Seine "Series" conglomerates are rarely foliated (except in ultramylonitic rocks). This is surprising in view of the fact that most plutonic rocks north of the QDZ are foliated in the present map area and elsewhere, judging from rock descriptions of other workers.

6 The Quetico and Seine River deformation zones host a variety of different rock types which include mafic as well as felsic volcanic material. These rocks are highly sheared and are locally carbonatized and contain abundant quartz veins and pods. Five of seven shafts have been sunk in these deformation zones and one past-gold producer, the Olive Mine, is situated in the QDZ west of the map area. This suggests that exploration should be concentrated within the major structural breaks.

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6. Project Unit 91–03. Geology of the Six Mile Lake Area

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INTRODUCTION

Geological mapping was undertaken on the Six Mile Lake Project, Savant-Sturgeon Lake area, northwestern Ontario, covering approximately 160 km^2 at a scale of 1:15 840. The Six Mile Lake project area is situated immediately north of the South Sturgeon Lake Volcanic Belt, host to the former producing Volcanogenic Massive Sulphide (VMS) Zn-Cu-Pb-Ag deposits at Mattabi, Sturgeon Lake and Lyon Lake (Figure 1). The area is bounded by latitudes 50°05'N and 49°56'N, and longitudes 91°00'W and 90°46'W (NTS 52G/15, J/2). The community of Savant Lake is 30 km north of the project area. Highway 599 provides access to the area from Ignace, Ontario. A logging-road network referred to locally as the Six Mile Lake road in conjunction with local lakes facilitate access to the entire area. Portions of the project area were previously mapped by Trowell (1974, 1976 and 1983).

The area was subject to a forest fire in the early 1980s and subsequent gale-force winds have created widespread "blow down" sections. A dense second growth of tightly spaced pine trees has camouflaged rock exposures and restricted access. Robinson and MacLean, in association with A.C.A. Howe International Ltd., were selected by the Ministry of Northern Development and Mines to map this area at a scale of 1:15 840.

GENERAL GEOLOGY

The area is underlain by an Archean supracrustal succession which forms a portion of the Wabigoon Subprovince granite-greenstone terrane (Trowell and Johns 1986). All supracrustal rocks are metamorphosed from greenschist to amphibolite facies; the prefix "meta" will henceforth be understood to apply to all rock types. The geology of the Six Mile Lake area consists of a south-facing, homoclinal sequence of two mafic to felsic volcanic cycles overlain by a third mafic volcanic cycle (Figure 2, 3). The lower mafic to felsic cycle is referred to as the Fourbay Cycle (FBC). The second mafic to felsic cycle is referred to as the Six Mile Lake Cycle (SMC) and the uppermost mafic cycle is the North Sturgeon Lake Cycle (NSC).

Mafic dikes, sills and sheets have invaded the SMC and are volumetrically abundant within this cycle. Quartz-feldspar porphyry and feldspar porphyry dikes and sills are also numerous throughout the second cycle. Two feldspar porphyry stocks, up to 1500 m by 5000 m, occur at and near the stratigraphic top of the second mafic cycle near King Bay and Six Mile Lake.

The volcanic succession is bounded to the north by felsic intrusive rocks of the Lewis Lake batholith. The third mafic cycle (NSC) is in disconformable contact with clastic sedimentary rocks of the Sturgeon Narrows Group (SNG), along the

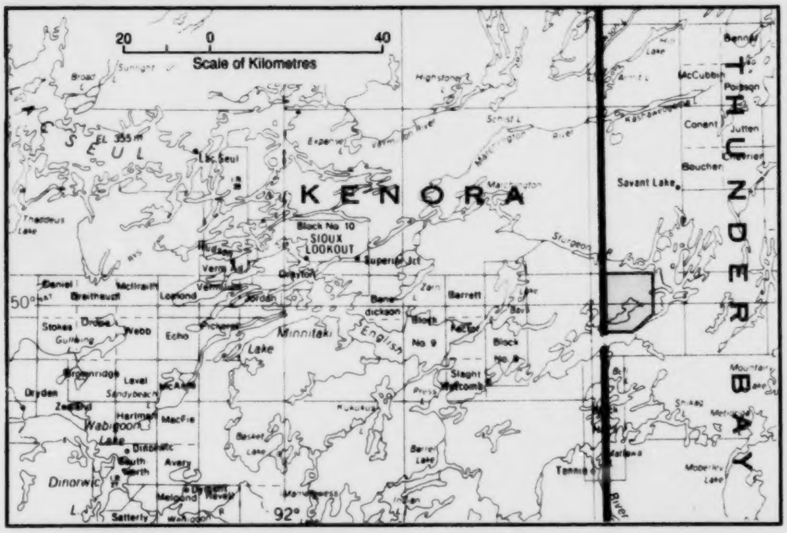

Figure 1. Location map of the Six Mile Lake area, scale 1:1 584 000.

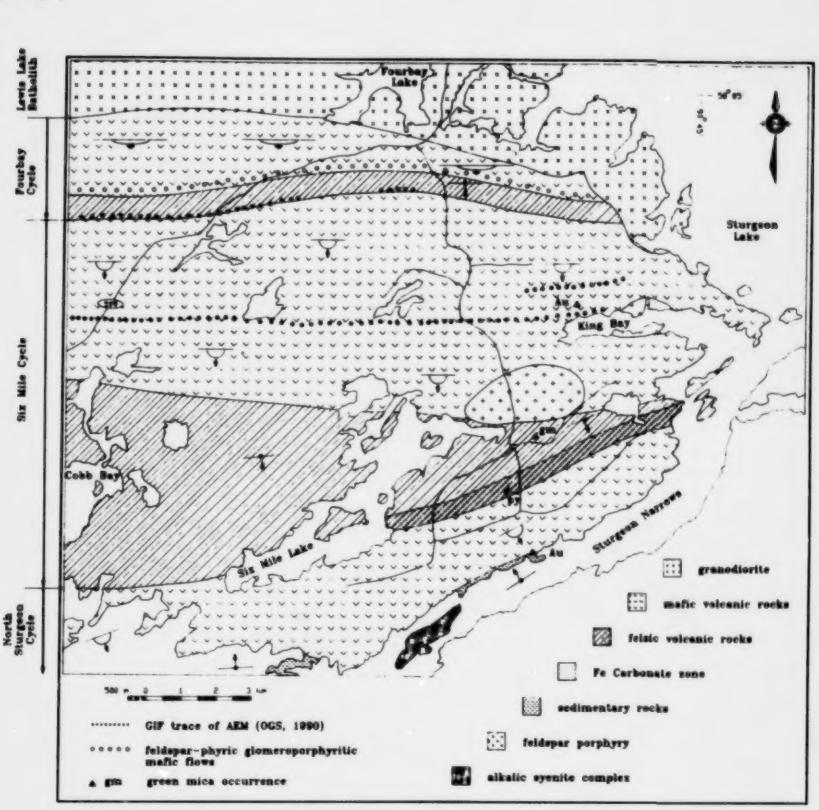
Lewis Lake Batholith
Fourbay Cycle
Six Mile Cycle
North Sturgeon Cycle
Fourbay Lake
Sturgeon Lake
King Bay
Cobb Bay
Six Mile Lake
Sturgeon Narrows
Au
gm
500 m 0 1 2 3 km
GIF trace of AEM (OGS, 1990)
feldspar-phyric glomeroporphyritic mafic flows
gm green mica occurrence
granodiorite
mafic volcanic rocks
felsic volcanic rocks
Fe Carbonate zone
sedimentary rocks
feldspar porphyry
alkalic syenite complex

Figure 2. Geological sketch map, Six Mile Lake area.

southern margin of the map area. The clastic sedimentary rocks have subsequently been invaded by the Sturgeon Narrows Alkalic Syenite complex. The stratigraphy throughout the succession faces south, excluding the SNG sedimentary rocks which face north.

FOURBAY CYCLE

The Fourbay Cycle comprises a 1500 m succession of mafic volcanic rocks which, from north to south, consist of a lowermost Banded Mafic Unit (BMU) overlain by a narrow Felsic Pyroclastic Unit (FPU cycle 1). Clastic sedimentary rocks have been observed within the Fourbay Cycle but do not form mappable units at a scale of 1:15 840. A feldspar-phyric glomeroporphyritic mafic unit, referred to as "leopard rock" by Trowell (1983), forms a regional stratigraphic marker horizon extending west across the entire map sheet and is situated immediately below the FPU (cycle 1). Semi-continuous sulfide-facies iron formation extends intermittently along the upper contact of the FPU (cycle 1), which is evident from field mapping and the recently completed airborne geophysical survey (OGS 1990).

Banded Mafic Unit (BMU)

The Banded Mafic Unit is in fault contact with the Lewis Lake felsic intrusive complex along the north boundary and extends across the map area, generally striking west and dipping steeply north. The BMU has an apparent thickness of 1000 to 1500 m and is characterized by pronounced compositional and colour banding. The banding is caused by differences in colour index and grain size between pillow interiors, margins and selvages. Pillow selvages form dark green, 1 cm wide, parallel bands composed of fine-grained chlorite, green amphibole and garnet. Pillow interiors form grey-green, 10 cm wide, amphibole-plagioclase-rich bands with a decreasing grain size from the centre to the margin of the band. Thin- and thick-banded rocks reflect a facies variation from pillowed flows with 10 cm wide bands to massive flows with greater than 2 m wide layers. Pillow forms become progressively attenuated northwards, with up to a 20:1 elongation ratio. There is also a general increase in deformation and metamorphic grade northward, from a greenschist-facies mineral assemblage south of the BMU to an amphibolite-facies assemblage within 1000 m of the felsic intrusive contact. Rare, felsic, pyroclastic and epiclastic sedimentary lenses, generally 1 or 2 m wide, are intercalated within the BMU. Elongated pillow selvages in granular-textured mafic flows are easily mistaken for isoclinally folded sedimentary rocks. Apparent isoclinal fold patterns are prevalent within the BMU and represent segments and terminations of elongated pillow rinds. Boudins and augen textures are also common within these attenuated pillowed flows, reflecting a ductile shortening in a northerly direction. The mafic flows at the top of the BMU are characterized by greenschist-facies mineral assemblages and pillow-elongation ratios of 3:1 or less, similar to the mafic volcanic stratigraphy in the overlying cycles 2 and 3.

Glomeroporphyritic mafic flows occur across the area of

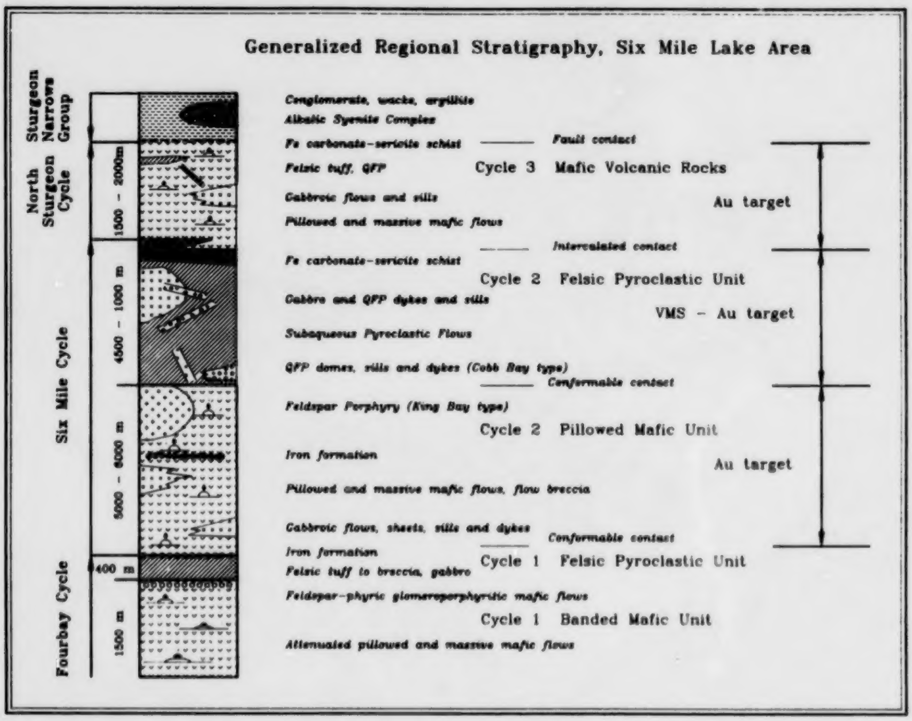
Generalized Regional Stratigraphy, Six Mile Lake Area
Sturgeon Narrows Group
North Sturgeon Cycle
Six Mile Cycle
Fourbay Cycle
1500 - 2000m
4500 - 1000 m
5000 - 6000 m
400 m
1500 m
Conglomerate, wacke, argillite
Albatic Syenite Complex
Fe carbonate-sericite schist
Fault contact
Felsic tuff, QFP
Cycle 3 Mafic Volcanic Rocks
Gabbroic flows and sills
Au target
Pillowed and massive mafic flows
Intercalated contact
Fe carbonate-sericite schist
Cycle 2 Felsic Pyroclastic Unit
Gabbro and QFP dykes and sills
VMS - Au target
Subaqueous Pyroclastic Flows
QFP domes, sills and dykes (Cobb Bay type)
Conformable contact
Feldspar Porphyry (King Bay type)
Cycle 2 Pillowed Mafic Unit
Iron formation
Au target
Pillowed and massive mafic flows, flow breccia
Gabbroic flows, sheets, sills and dykes
Conformable contact
Iron formation
Felsic tuff to breccia, gabbro
Cycle 1 Felsic Pyroclastic Unit
Feldspar-phyric glomeroporphyritic mafic flows
Cycle 1 Banded Mafic Unit
Attenuated pillowed and massive mafic flows

Figure 3. Generalized regional stratigraphy, Six Mile Lake area.

the map sheet, at or near the contact with the overlying felsic volcanic rocks. White-weathering, subrounded, feldspar glomerophenocrysts comprise from 5 to 50% of the rock and vary in size from 5 mm to 5 cm. Glomeroporphyritic mafic flows, dikes and sills are found elsewhere within the map sheet.

Felsic Pyroclastic Unit (FPU cycle 1)

A 400 to 500 m wide sequence of felsic pyroclastic rocks, capping the Fourbay cycle, has been traced across the map area. Exposure of this unit is limited to a few outcrops on any one traverse, but on each traverse, one or more exposures of pyroclastic rock were consistently found across this interval. The FPU (cycle 1) consists dominantly of crystal tuff and lapilli tuff, with lesser amounts of pyroclastic breccia, tuff-breccia and fine ash deposits of intermediate to felsic composition. Graded bedding and scour marks are indicative of a south-facing sequence.

The FPU is made up of greater than 50% fine- to coarse-grained mafic intrusive rock, devoid of any flow textures. Several exposures of sulfide-facies iron formation and chert were located at or near the top contact of the FPU (cycle 1). A semi-continuous, airborne-electromagnetic-conductive marker horizon is evident along the top FPU (cycle 1) contact; it is presumably indicative of iron formation (Figure 2, 3; OGS 1990). This felsic unit represents a discrete time horizon and a change in volcanism from a mafic flow-dominant regime to a short-lived explosive felsic pyroclastic phase, followed by an interval of quiescence.

SIX MILE LAKE CYCLE

The Fourbay Cycle is conformably overlain by a second mafic to felsic volcanic cycle referred to as the Six Mile Cycle (SMC). The Six Mile Cycle consists of a 10 000 to 12 000 m thick bimodal sequence commencing with a lower pillowed mafic unit (PMU) overlain by a upper felsic pyroclastic unit (FPU cycle 2). A west-trending iron formation bisects the lower mafic cycle parallel to the north shore of King Bay (Figure 2 and 3; *see also* OGS 1990). Quartz-feldspar porphyry and feldspar porphyry occur as dikes and sills throughout the SMC. Two feldspar porphyry stocks intrude the mafic succession and coincide with a small gold deposit at King Bay and at the top of the mafic volcanic pile (Figures 2 and 3). A small granodiorite stock also intrudes the mafic sequence at the centre of the map area near Jumping Lake.

Pillowed Mafic Unit (PMU)

The lower half of the Six Mile Cycle is dominated by a thick sequence of well-developed pillowed flows, flow breccia and thin to thick massive flows. The PMU strikes west, dips steeply north and is approximately 5000 to 6000 m thick. Primary textures are locally very well preserved, including sequences of lower massive flow bases immediately overlain by mattress- and tube-size pillows capped by pillow flow breccia. Facing directions throughout the section are consistently south.

The pillowed units are generally vesicular/amygdaloidal with interstitial quartz filling pillow interstices and half-moon shaped, quartz-filled structures within pillow interiors. Pillowed flows at the top of the PMU are amygdaloidal with well-developed pipe-like vesicles, 1 or 2 cm long, possibly indicative of a shallow-water eruptive environment (Glen Johns, Ontario Geological Survey, personal communication, 1991). Franklin (1977) also noted an increase in the vesicularity of the mafic flows towards the top of the south Sturgeon volcanic pile. The mafic volcanic succession is remarkably uniform in composition and generally unaltered (Beggs 1975).

Alteration in the lower half of the PMU is generally confined to patches of epidote and interstitial quartz material within flow top breccia and pillow interstices. Silicified and carbonatized mafic flows, indicated by white and brown weathered surfaces, respectively, occur near the north end of Six Mile Lake at the top of the mafic volcanic pile. Mafic volcanic rocks in the King Bay area are generally more chloritic than elsewhere in the map area; this is especially evident on the weathered surface.

Felsic Pyroclastic Unit (FPU Cycle 2)

Cycle 2 felsic pyroclastic rocks form a west-trending, westward-thickening wedge, dominated by pyroclastic deposits, quartz-feldspar porphyry and a substantial proportion of gabbro dikes and sills (Figures 2 and 3). In general, the SMC felsic volcanic cycle displays an upward- and eastward-fining sequence implying a transition from a proximal to distal setting (Easton and Johns 1986). Younging directions within the FPU (cycle 2) are consistently south, as indicated by graded bedding. Rare, narrow-pillowed flow units have been mapped within the FPU (cycle 2). A distinct Fe-carbonate alteration zone marks a favourable target for mineral exploration along the upper contact (Figures 2 and 3). Abundant green mica was also observed within felsic fragmental rocks stratigraphically above the feldspar porphyry stock east of Six Mile Lake.

The felsic volcanic rocks range from coarse to fine pyroclastic deposits including pyroclastic breccia, tuff breccia, lapilli tuff, crystal tuff (coarse ash) and tuff (fine ash). The felsic stratigraphy is dominated by thick-bedded coarse ash deposits. In several localities well-preserved submarine ash flows, characterized by basal block and ash layers (Photo 1), overlain by bedded coarse ash (Photo 2) and capped by fine ash layers (Photo 3) have been observed. Graded bedding is apparent within individual members illustrating a south-facing succession (Photo 2 to 4). These composite ash flows are generally less than 30 to 50 m thick from base to top and display a cyclical repetition of coarse to fine layers which are doubly graded, similar to the subaqueous pyroclastic flows in Japan described by Fiske and Matsuda (1964). The ash flows contain up to 90% felsic juvenile fragments which are aphanitic, commonly quartz-phyric, white weathering and vesicular, ranging from large blocks (greater than 250 mm) to coarse ash (4 mm; Photos 1 to 4). Accidental fragments are a minor constituent, generally sericitized, commonly plagioclase-phyric, tabular to elongate, possibly pumiceous and of intermediate composition.

Thin (less than 20 cm), black argillaceous layers locally cap the composite ash-flow unit, indicative of a subaqueous depositional environment.

Gabbro Unit

Numerous sills and dikes of gabbro occur within the Six Mile Cycle. Locally, greater than 50% of the stratigraphy is composed of fine- to coarse-grained gabbro. Gabbro exposures are massive to porphyritic, devoid of any volcanic flow textures and difficult to distinguish from massive mafic flows. Rafts of felsic volcanic material (FPU cycle 2), up to 10 m across,

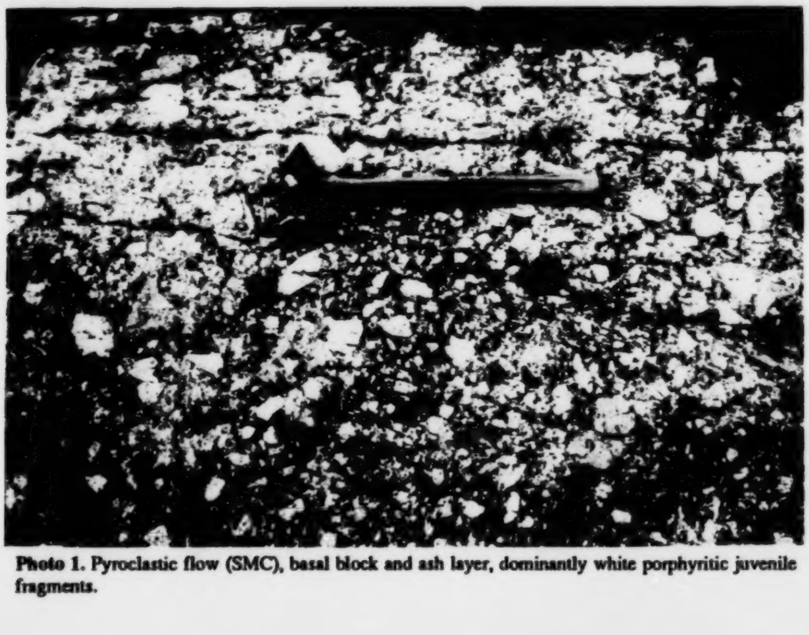

Photo 1. Pyroclastic flow (SMC), basal block and ash layer, dominantly white porphyritic juvenile fragments.

Photo 2. Pyroclastic flow (SMC), doubly-graded bedded block and ash layers, coarse ash layers (dark beds) and fine ash layers (light beds).

Photo 3. Fine ash deposit (SMC), graded bedding with fine to coarse ash (dark beds) capped by fine cherty tuff layers (light beds).

are contained within gabbro; they are aligned parallel to the regional trend of cycle-2 felsic volcanic rocks. Layering and jointing within the gabbro is north oriented.

King Bay Feldspar Porphyry

Two feldspar porphyry stocks occur at and near the stratigraphic top of the PMU, referred to as King Bay-type Feldspar Porphyry (FP). This porphyry is characterized by a fine-grained, andesitic to dacitic, foliated, quartzo-feldspathic matrix with 5 to 25%, 2 to 10 mm, white, tabular plagioclase phenocrysts. Mafic volcanic inclusions are ubiquitous and smokey grey quartz eyes constitute less than 2% of the phenocryst component. The King Bay FP comprises part of the host rock for the King Bay gold occurrence (Figures 2 and 3).

Cobb Bay Quartz-Feldspar Porphyry

Quartz-feldspar porphyry (QFP, Cobb Bay type), dikes, sills and small stocks are common throughout the felsic succession. Notably, small QFP stocks or domes are abundant near the FBC/SMC volcanic contact, west of Six Mile Lake. The Cobb Bay QFP differs from the King Bay FP in being more siliceous, with 2 to 5%, 2 to 5 mm, subrounded quartz phenocrysts and 5 to 15%, 2 to 4 mm, subhedral white plagioclase crystals within a fine-grained quartz-feldspar dacitic to rhyolitic ash matrix.

Fe-Carbonate Zone

Felsic crystal tuff is pervasively altered to a quartz + sericite + Fe-carbonate schist forming a 9000 m long Fe-carbonate alteration and deformation zone along the top contact of the eastern half of the SMC (Figure 2). These distal felsic volcanic rocks host a small, barren, massive pyrite deposit previously drilled for base metals (*see* Mineral Exploration section below). Orange-brown carbonate occurs intercalated as narrow-bedded layers (less than 1 m) and interstitial to felsic quartz-phyric ash flow layers.

NORTH STURGEON LAKE CYCLE

The Six Mile Cycle is conformably overlain by a third cycle of mafic volcanic rocks of the North Sturgeon Lake Cycle (NSC) formerly of the Central Sturgeon Lake Cycle (Chart A, Figure 2, Trowell 1983). These mafic rocks are locally interfingered with SMC felsic pyroclastic rocks and consist mainly of fine- to medium-grained flows, flow breccia, pillowed flows and amygdaloidal flows. Unlike the SMC pillowed flows, pillow forms within the NSC are smaller bun to tube size, with thin pillow selvages. Similar to the SMC felsic rocks, NSC mafic rocks form a 70°- to 110°-trending, easterly thinning, steeply dipping, south-facing wedge, ranging from 1500 m to 2500 m thick. Chlorite-carbonate schist outcrops along the

Photo 4. Pyroclastic flow (SMC), block and ash beds alternating with coarse and fine ash beds. Note cross-bedded layer near hammer, possible base surge deposit.

north shoreline of Sturgeon Lake. Faulting and shearing is evident along the shoreline of Sturgeon Narrows, marking the upper limit of the NSC.

Several thin (less than 100 m), felsic pyroclastic exposures have been mapped near the top of the NSC mafic succession, although the felsic stratigraphic component is volumetrically minor. Felsic volcanic rocks were identified below Sturgeon Lake by drilling. A heterolithic fragmental unit of intermediate to felsic composition occurs along the north shore of a "dog-leg" shaped peninsula on Sturgeon Lake in contact with sedimentary rocks (Figure 2). The heterolithic unit is composed principally of polymictic volcanic clasts ranging from crystal-size to 1 m long blocks, hosted by an intermediate volcanic matrix.

STURGEON NARROWS GROUP

The volcanic stratigraphy of the Six Mile Lake area is disconformably overlain by northeast-trending, steeply dipping, north-facing wacke and conglomerate of the Sturgeon Narrows Group (SNG). Sedimentary exposures are confined to the shoreline and islands within Sturgeon Narrows (Figure 2). Thick-bedded green wacke, characterized by a fine-grained, quartzo-feldspathic matrix, is locally intercalated with thinly laminated argillite. Polymictic conglomerate exposures contain subrounded, pebble- to boulder-sized mafic to felsic clasts and to a lesser extent contain intrusive clasts within an intermediate volcanic matrix. Rare jasper clasts are also present. Orientations of graded bedding, cross bedding and flame structures within wacke and argillite indicate a north-facing sequence.

LEWIS LAKE BATHOLITH

The volcanic sequence of the project area is bounded to the north by felsic intrusive rocks of the Lewis Lake Batholith. These foliated to gneissic syntectonic felsic intrusive rocks consist of medium- to coarse-grained, massive, banded and porphyritic, quartz-feldspar-hornblende-biotite granodiorite to leucotonalite. Pegmatite and aplite dikes are common within both the felsic intrusive suite and the adjacent FBC mafic volcanic rocks. Foliation within the felsic intrusive rocks is concordant to the FBC mafic suite along the north boundary. However, the eastern margin of the FBC is truncated by the batholith (Figure 2).

STURGEON NARROWS ALKALIC COMPLEX

The Sturgeon Narrows sedimentary rocks have been intruded by an alkalic syenite, confined to the southeastern boundary of the map area (Figure 2). The alkalic complex consists of massive- to trachytic-textured, grey to brick-red megacrystic feldspathic syenite. The alkalic complex is described by Trowell (1983) and Trowell et al. (1979). Fluorite is present locally as an accessory mineral. No alkalic volcanic rocks similar to the Kirkland Lake camp were observed in the map area.

STRUCTURAL GEOLOGY

The volcanic succession of the Six Mile Lake area forms a south-facing homoclinal sequence, as determined from sedimentary structures, pillow tops and layered composite units. Composite units include sequences of massive flows overlain by pillowed flows capped by flow breccia and coarse felsic fragmental beds conformably overlain by coarse ash-flow layers and thin-bedded fine ash deposits.

Stratigraphic directions throughout the PMU face south; however, the unit dips north and thus is overturned. Primary layering within the FPU (cycles 1 and 2) displays graded bedding and flame and scour textures also indicative of a southerly younging direction. Volcanic textures within the SMC mafic and felsic suites are remarkably well preserved (Photos 1 to 4).

Graded bedding and cross-bedding within SNG sedimentary rocks support a north-younging stratigraphic sequence. Unlike the sedimentary rocks within the East Bay (Williams and Nacha, this volume), poly-phase deformation patterns are not prevalent within sedimentary rocks in the map area along the Sturgeon Narrows.

Feldspar megacrysts within the Sturgeon Narrows Alkalic Complex display a trachytic texture which, according to Trowell (1976), may represent a primary igneous structure.

Schistosity is well developed within the felsic pyroclastic rocks (FPU cycles 1 and 2), with a general alignment of sheet silicate minerals at an oblique angle to bedding. Chlorite, sericite and carbonate schists mark zones of alteration and deformation along the south shoreline of Six Mile Lake, the top contact of SMC, and the north shoreline of Sturgeon Lake, bounding the NSC mafic suite. Graded bedding in thinly laminated argillite-wacke layers is crosscut by an oblique S_1 cleavage aligned counter-clockwise to bedding, indicative of a northeasterly structural facing within the sedimentary rocks of the SNG.

The banded mafic unit of the FBC displays a progressive deformation signature within 1000 m of the Lewis Lake Batholith, with a concomitant change from a greenschist to amphibolite facies mineral assemblage, constituting a metamorphic and strain aureole. Localized deformation within the BMU and the adjacent granodiorite occurs as less than 1 m wide, dextral shear zones along contacts or other anisotropic features which have taken up the ensuing strain during deformation (Williams and Nacha, this volume). The granodiorite/volcanic rock contact is also a dextral shear zone. S and Z forms, abundant within the BMU, represent segments of elongated pillow rinds. A 30 to 50 cm wide sinistral shear zone is exposed in a small trench 100 m north of the King Bay gold deposit (Williams and Nacha, this volume). These shear zones do not constitute mappable structures at a scale of 1:15 840.

MINERAL EXPLORATION

The Six Mile Lake area has undergone two major episodes of exploration activity, respectively, for base metals and gold. Discovery of the volcanogenic massive sulfide (VMS) Zn-Cu-Pb-Ag deposits at Mattabi in September of 1969 and at Sturgeon Lake in October 1970 (Harvey and Hinzer 1981; Severin 1982), sparked a wave of exploration for base metals in the late 1960s and early 1970s. A massive pyritic sulfide lens up to 5 m thick, hosted by felsic pyroclastic rocks within the Fe-carbonate zone (Figure 2), was geologically surveyed in 1973 by Santa Maria Mines Ltd. and diamond drilled in 1985 by International Santana Resources. The sulfide lens coincides with a 1200 m long induced polarization (IP) anomaly. Only trace amounts of base and precious metals were found. However Cunningham et al. (1984) suggested that the geological setting of the Agnico-Eagle gold deposit near Joutel, Quebec, is similar to the Santa Maria property. Rio Tinto Exploration Ltd. (1970–71) and Granges Ltd. (1972) also completed massive sulfide exploration programs within the Six Mile Lake area.

The rediscovery of gold in the early 1980s at King Bay, by prospectors Armstrong and Best, instigated a second episode of exploration within the Six Mile mafic volcanic package.

A small gold deposit has been outlined immediately north of King Bay consisting of visible gold contained within blue-grey quartz veins hosted by chloritized and carbonatized pillowed and massive mafic flows. Initial drilling from north to south included the following results: KB–3, 0.127 ounces Au per ton across 12.5 feet.; KB–4, 1.34 ounces Au per ton across 29.7 feet. and KB–5, 0.864 ounce Au per ton across 15.3 feet. These three holes tested the occurrence over a strike length of 50 m and to a depth of 50 m.

Several drilling campaigns have subsequently tested the deposit and surrounding area, including: Armstrong–Best (14 holes, 4760 feet.); Steep Rock Resources (1982, 20 of 45 holes, 20 131 feet.); Hudson Bay Exploration (1984, 4 holes, 3186 feet.); Falconbridge Ltd. (1986, 5 holes, 3138 feet.) and Almaden Resources (1987, 11 holes, 2830 feet.). Hudson Bay Exploration (1984) reported that the stratigraphic section of the deposit consists principally of massive and pillowed mafic flows, with very minor QFP, chert, tuff and wacke. Hudson Bay also indicated that the gold zone was hosted within westerly plunging, narrow and irregular blue quartz veins coincident with a marker horizon of sulfide-facies iron formation. Almaden Resources Corporation (1987) stated that the deposit was confined to a steeply south-dipping structure composed of grey to buff, altered mafic flows. Almaden reported that the alteration zone averaged 7 m in width, composed of carbonate, sericite, talc and 1 to 2% pyrrhotite. Furthermore, they concluded that the initial drill intercepts (KB–3 to KB–5) probably intersected the auriferous blue-grey quartz vein down dip. Both Hudson Bay Exploration and Almaden Resources Corporation intersected gold values over narrow widths, drilling north.

Several other gold exploration programs were undertaken in the area based on the discovery at King Bay, principally within the PMU of the Six Mile Cycle. Exploration for gold has also occurred in the vicinity of Hook peninsula, along the north shore of Sturgeon Narrows. Sedimentary rocks crosscut by an alkalic syenite dike are pervasively carbonatized and contain quartz veins and disseminated pyrite. Grab samples have assayed up to 1.03 ounces Au per ton and trench samples up to 5800 ppb Au (Abermin Corp., 1986–1989). Drilling campaigns by W.G. Wahl Ltd. (1969, 6 holes, 5196 feet.), Falconbridge Nickel (1974, 2 holes, 608 feet) and Primrose Gold (1988–89) have tested the Hook peninsula property with limited success.

The Ontario Geological Survey completed an airborne magnetic and electromagnetic survey over the entire area in 1990 defining two or more semi-continuous conductive horizons, locally coincident with sulfide-facies iron formation, as at King Bay. Geological Data Inventory Folios have also been completed for the map area (OGS 1986, 1987).

DISCUSSION AND RECOMMENDATIONS

Greenstone belts may locally contain supracrustal assemblages with tectonic rather than stratigraphic contacts according to Sanborn-Barrie (1990) and Davis et al. (1988). Tectonic juxtaposition of assemblages may result in "out of sequence" stratigraphy (Sanborn-Barrie 1990). In the Six Mile Lake area there is evidence for two or more tectonic assemblages in the map area, with different boundaries than originally interpreted by Trowell (Chart A, Figure 2, 1983). The volcanic-sedimentary stratigraphy previously defined by Trowell (1983) included a North, South and Central Sturgeon Lake Assemblage, which in turn was further subdivided into volcanic cycles (*see* Trowell 1983, Chart A, Figure 2). Trowell (1983) subdivided the North Sturgeon Lake Assemblage into two volcanic cycles including the Fourbay Lake Cycle and the Jumping-Six Mile Lakes Cycle. The third volcanic cycle (NSC) in the map area (this study) was grouped within the Central Sturgeon Lake assemblage by Trowell (1983). The contact between the felsic volcanic rocks of the second cycle (SMC) and the overlying mafic flows of the third volcanic cycle (NSC) is intercalated, indicative of a continuum. However, there is a clear break in volcanism, with opposing stratigraphic facing directions between the third volcanic cycle (NSC) and the sedimentary rocks of the Sturgeon Narrows Group. Accordingly, the southern boundary between tectonic assemblages should be located at the top of the third volcanic cycle.

The Fourbay Cycle is 30 million years older (2775 ±1 Ma; Davis et al. 1988), than the Handy Lake sequence from the Savant Lake area. Dacitic tuff near the base of the Handy Lake volcanic rocks yields dates of 2745 ±2 Ma (Davis and Trowell 1982). The Handy Lake sequence within the Northeast Arm appears correlative with the Six Mile Lake Cycle, based on comparable geology, stratigraphic facing directions and continuity of the airborne magnetic data (Williams and Nacha, this volume). Consequently the Fourbay Cycle may represent a separate tectonic assemblage, but in this case it does not appear to be out of sequence. There is also a 10 million year gap between the absolute ages of the Handy Lake sequence and the Mattabi-Lyon Lake Mine stratigraphy (2735 ±1.5 ma.; Davis et al. 1985). Davis and Trowell (1982) suggested that the 27 Ma difference in age between the South Sturgeon Lake Cycle (2718 ±2 ma) and the Handy Lake sequence indicated that they were deposited by separate volcanos. By inference, the Six Mile Lake Cycle was deposited by a volcano other than that responsible for the mine stratigraphy.

Felsic volcanic rocks along the shoreline of Sturgeon Lake (South Shore Cycle 4, see Chart A, Figure 2, Trowell 1983) which overlie the Lyon Lake–Creek Zone–Sturgeon Lake VMS deposits, and the Mattabi F Group stratigraphy were briefly examined for comparative purposes. The entire South Sturgeon Lake volcanic pile consisting of four mafic to felsic volcanic cycles has a thickness equivalent (9000 to 10 000 m, Groves et al. 1988; Davis et al. 1985; Trowell 1983) to the second volcanic cycle (SMC) in the Six Mile Lake area. However the South Sturgeon Lake volcanic pile displays a much greater diversity in lithology over a similar interval. Morton et al. (1991) have demonstrated that the six VMS deposits at Sturgeon Lake are hosted within submarine ash-flow tuffs post-dating caldera collapse. Pre-caldera stratigraphy at Sturgeon Lake below the Mattabi and F Group deposits, including pyroclastic-ash-flow and ash-fall deposits, is indicative of a subaerial- to shallow-water environment (Morton et al. 1991; Groves et al. 1988), whereas pillowed and amygdaloidal mafic flows at Six Mile Lake reflect a deeper subaqueous regime. Collapse and caldera-fill deposits including the mega- and meso-breccias at Sturgeon Lake were not observed at Six Mile Lake. The Mattabi ores are hosted within deeper-water, subaqueous bedded quartz-crystal pyroclastic flow deposits, overlain by massive shallower-water ash-flow tuffs according to Morton et al. (1991). Bedded and massive ash-flow deposits of comparable morphology and size to the immediate host rocks at Mattabi are present within the second cycle at Six Mile Lake.

Although there are general similarities in rock type between felsic volcanic rocks of the South Shore Cycle, mine stratigraphy and the Six Mile Lake Cycle, the aluminous mineral assemblages which characterize the rock alteration within the mine stratigraphy (Groves et al. 1988; Franklin et al. 1975; Franklin 1984) are absent within the Six Mile Lake Cycle. Unlike the Noranda-type VMS deposits (Morton and Franklin 1987), a semi-conformable zone of iron carbonate is abundant within the footwall of the Mattabi mine, according to Franklin (1984). Similarly, an iron-carbonate alteration zone caps the SMC felsic pyroclastic unit, locally containing massive pyritic sulfide. These carbonate-rich rocks within the SMC are also potential host rocks for a Bousquet-type distal felsic volcanic-hosted pyritic gold deposit, as described by Valliant et al. (1982).

Several stratigraphic/structural settings within the Six Mile Lake area are prospective for gold. The King Bay occurrence illustrates an association of gold with carbonatized mafic volcanic rocks and porphyry, perhaps akin to the Porcupine camp or Red Lake camp (Dunbar 1948; Pirie 1982). The iron formation may mark a stratigraphic and structural "break" spatially associated with gold at King Bay. This relationship occurring across the area of the map sheet is recommended for exploration. The gold intercepts presently known are within narrow and irregular quartz veins. However the "lodes" have not been discovered to date.

The contact between the volcanic pile and Sturgeon Narrows group may be analogous to a Kirkland Lake setting as indicated by coarse clastic sedimentary rocks (Timiskaming equivalent?) situated in a fault-bounded trough invaded by an alkalic syenite. Carbonate alteration, disseminated pyrite and quartz veins are found locally in association with gold. The setting may be more prospective along strike to the northeast.

The distal setting of the SMC felsic pyroclastic unit associated with feldspar porphyry, green mica, carbonate alteration and massive sulfide is a prime target for gold. The western half of the SMC represents a more proximal VMS environment; however there are no isolated aerial electromagnetic conductors to act as a focal point. Petrographic and geochemical studies, in progress, are aimed at establishing alteration indices for gold and VMS deposits.

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7. Project Unit 91–05. Re-assessment of the Northern Part of the Sturgeon Lake Region, Districts of Kenora and Thunder Bay

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INTRODUCTION

The project area (*see* Figures 1 and 2) includes the northern part of Sturgeon Lake, from Sturgeon Narrows at latitude 50°N, northward to the Canadian National Railway line that connects Savant Lake with Armstrong. The rocks studied included the northern part of the Sturgeon Lake greenstone belt and its bordering granitoids.

Rationale of Project

A recent review of stratigraphic and geochronological data for the western Wabigoon Subprovince (Blackburn and Johns, in press) indicated that problems of stratigraphic correlation and greenstone belt structure exist in the Sturgeon Lake region.

An earlier study of the Savant Lake area by Sanborn-Barrie (1989, 1990, 1991) re-investigated the Savant Lake greenstone belt and was instrumental in determining its structure, and providing detail on the occurrence of conglomerate that served as marker units. Her work also indicated a need for a similar study in the Sturgeon Lake region to the south.

A combination of new stratigraphic and structural data may aid in correlation of the productive mineralized units in the southern part of Sturgeon Lake with similar rocks in other parts of the region; thereby focussing exploratory effort.

Objectives

The objectives of this study are to develop an understanding of the structure of the northern portion of the Sturgeon Lake greenstone belt in a manner similar to that carried out in the Savant Lake area by Sanborn-Barrie (1991). Such an understanding is critical to the stratigraphic correlation and structural relationships of the several mafic and diverse mafic to felsic volcanic units; some of these have been shown to be of differing age. These relationships have not previously been fully documented.

Techniques

It is not the intention of this project to remap the region completely, nor has this been deemed necessary. Time constraints on the project allowed only rapid reconnaissance techniques involving detailed examination of large outcrops on lakeshore

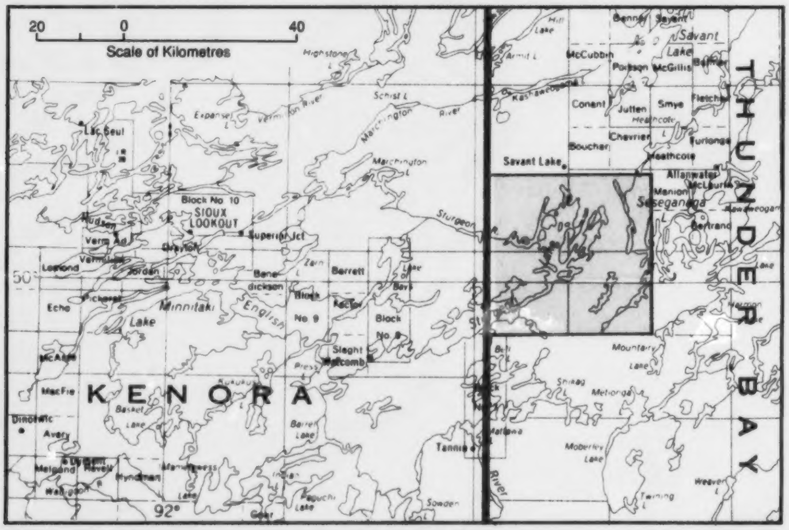
20
0
40
Scale of Kilometres
KENORA
THUNDER BAY
Lac Seul
Block No 10
SIOUX LOOKOUT
Superior Jct
Savant Lake
Sturgeon
Marchington River
Vermilion River
Schist L
Minnitaki Lake
English
Block No 9
Block No 8
Savant Lake
Sesegananga L
Mountain Lake
Moberley Lake
Tannin
River
50°
92°

Figure 1. Location map of the study area, scale 1: 1 584 000.

and road sections, selected traverses across the belt, and compilation of existing data. Measurements of structural features, such as planar and linear fabric data, were collected throughout the region; fold geometry and fold/fabric chronology were established and description of shear zones included their geometry and kinematics.

Localized detailed study of some clastic units has resulted in some being re-interpreted as felsic volcanic, rather than sedimentary in origin.

MINERAL EXPLORATION

Significant base metal and gold exploration activity has taken place in this region over the last 90 years (Figure 2). Whereas property acquisition demonstrates that interest continues, large-scale exploration activity is presently restricted to the search for gold in sedimentary rocks in the southeastern portion of the region.

Gold occurrences in the region are mainly concentrated in or adjacent to contact zones between mafic volcanic rocks and late stage granitoid intrusions that separate the greenstone belt from the complex tonalitic to mafic intrusions of the Lewis Lake batholith (*see* Figure 2, localities A-C). Gold mineralization is associated with magnetite- and sulphide-bearing quartzite found within what have hitherto been inferred to be clastic metasedimentary rocks in East Bay (Figure 2, locality D) and south and east of Vista Lake. Gold is also found in association with both small and regionally extensive, sheared and carbonate-altered zones in mafic volcanic rocks, as for example, in the trenches north of King Bay (Figure 2, locality E).

Base metal mineralization of the type typically found within highly altered felsic volcanic rocks or at the contact between felsic and mafic volcanic rocks was not found in the region. Alteration zones characterized by the presence of highly aluminous minerals are apparently developed only at Mattabi and Lyon lakes, and in the region between Savant and Sturgeon lakes. Small occurrences of base metal mineralization are described herein. They occur both in association with a small discordant magmatic breccia (Figure 2, locality F) and in undeformed granitic pegmatites (Figure 2, locality G) within the Lewis Lake batholith.

ROCK TYPES AND THEIR DISTRIBUTION

Only a brief review is offered here, for all rock types have been fully documented by Trowell in his numerous publications and maps (e.g., Trowell 1983b). In order to reduce potential confusion to a minimum, we have adopted, with minor modification, the map legend developed by Trowell in his 1:50 000 compilation map series (Trowell 1983a).

Mafic Volcanic Rocks

A range of well-preserved, relatively undeformed pillowed and massive flows, autoclastic breccia and tuff are exposed in the region (Figure 2). In regionally extensive shear zones, and especially close to the eastern margin of the greenstone belt, the supracrustal rocks of the greenstone belt are commonly highly schistose and primary features are rendered unrecognizable. Many decimetre-scale shear zones appear to be located at or close to fine–grained rocks at the tops of only mildly elongated mafic flow units and are, therefore, an example of the lithological control of strain state.

Felsic Volcanic Rocks and Associated Sedimentary Rocks

Coarse to fine clastic volcanic rocks in the form of tuff, lapilli tuff and tuff breccia separate the major units of mafic volcanic rock (Figure 2). Some tuffs contain angular fragments of dark-coloured cherty material (Figure 2, locality P). A wide variation in grain size from tuff breccia containing metre-scale blocks, to very fine-grained, white cherty tuff occur within a small area (Figure 2, locality Q). All these rocks are variably deformed, but large areas show little deformation. Deformed equivalents exhibit a strong schistosity, contain elongate clasts and, as a result of the formation of muscovite and carbonate, become pale orange to chocolate brown in colour (Figure 2, locality H). Blocks of this highly altered material occur in stratigraphically overlying units of felsic tuff breccia (Figure 2, locality R).

No new areas of pervasive alteration of quartzo-feldspathic rocks to aluminous mineral assemblages were noticed. In shear zones, muscovite-bearing, deformed equivalents of tuff and breccia were recorded (Figure 2, locality I). Elsewhere, hornblende-bearing veins, pods and layers are typically developed in tuffs, these too have been deformed (Figure 2, locality S). Carbonate alteration (cf. carbonate-breccia unit of Trowell 1983b) was noted in association with shear zones and at the contacts of mafic and felsic volcanic units in the Northeast Arm of Sturgeon Lake (Figure 2, locality H).

Some sedimentary rocks in East Bay and along the eastern edge of the greenstone belt (Trowell 1983b), consisting of leucocratic fine- to medium-grained layered tuffs (Figure 2, locality J) and rare monolithic poorly sorted tuff breccia (Figure 2, locality K), have been reassigned a felsic volcanic origin. There are still some instances, however, where bedded, leucocratic clastic rocks have not been definitely assigned a volcanic origin, or where they are interbedded, on a scale of metres, with dark grey lithic wackes.

Monolithic felsic tuff breccia has been recognized in the region of Vanessa, Wellington and Beckington lakes (Figure 2, locality K). Mostly, these tuff breccias are monolithic and clasts do not represent a selection of rock types derived from the volcanic substrate as might be expected if the rocks were of sedimentary origin.

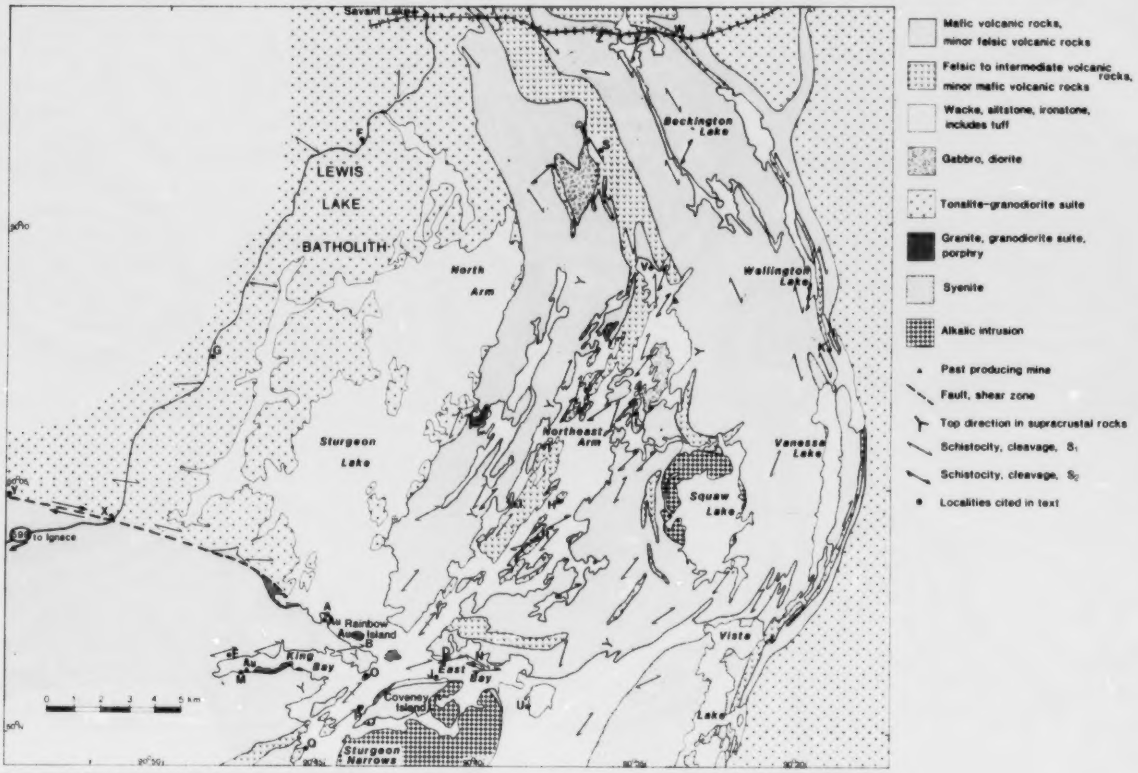
Savant Lake
Beckington Lake
LEWIS LAKE BATHOLITH
North Arm
Wellington Lake
Sturgeon Lake
Northeast Arm
Vanessa Lake
Squaw Lake
Rainbow Island
King Bay
East Bay
Coveney Island
Sturgeon Narrows
Vista Lake
599 to Ignace
0 1 2 3 4 5 km
Mafic volcanic rocks, minor felsic volcanic rocks
Felsic to intermediate volcanic rocks, minor mafic volcanic rocks
Wacke, siltstone, ironstone, includes tuff
Gabbro, diorite
Tonalite–granodiorite suite
Granite, granodiorite suite, porphyry
Syenite
Alkalic intrusion
Past producing mine
Fault, shear zone
Top direction in supracrustal rocks
Schistocity, cleavage, S1
Schistocity, cleavage, S2
Localities cited in text

Figure 2. Geological sketch map of the northern part of the Sturgeon Lake region; modified after Trowell (1983a).

Clastic Sedimentary Rocks

The re-assessment of the region has shown that some of rocks considered to be sedimentary in origin are more properly part of a proximal facies tuff breccia to distal facies tuff and lapilli tuff sequence. Some rocks previously considered to be conglomerate are now assigned an origin as volcanic tuff breccia.

In Beckington Lake (Figure 2, locality W) and Wellington Lake areas, quartzo-feldspathic, arenaceous clastic rock, originally mapped by Trowell (1981) as sedimentary, we now consider to be felsic tuff, and has therefore been described under the previous heading. Similarly, in the Vanessa Lake region, rocks rich in monolithic fine- to medium-grained leucocratic clasts are now considered to be felsic volcanic tuff breccia.

In the East Bay area, dark grey lithic and feldspathic wacke, siltstone and graphitic argillite appear to be interbedded with the tuffaceous rocks described above.

Mafic Intrusions

Bodies of gabbro, leucogabbro, and diorite are spatially associated with both mafic and felsic volcanic rocks. They are considered to be intrusive, but this is commonly hard to determine; some may be coarse-grained mafic flows. Bodies of gabbro, rarely feldspar-phyric (Figure 2, locality L), up to several hundred metres thick and several kilometres long were mapped by Trowell (1983a, 1983b). Mafic intrusions, including bodies several decimetres to several hundred metres thick, have been emplaced within the felsic volcanic pile. Some of these are demonstrably discordant, others are concordant; all show some signs of deformation, especially at their margins.

Magnetitic and Sulphidic Ironstone

Finely laminated to decimetre-bedded quartz-magnetite and quartz-pyrite rocks and associated pelite occur within both mafic volcanic and sedimentary rocks in the region. It is not clear from field observations whether the sulphide is primary. Many of these rocks are highly tectonized, consisting of blocks of quartzite in a matrix of sulphidic, graphitic and pelitic material. Examples of these rocks occur in King Bay and East Bay (Figure 2, localities M and N, respectively) and form thin layers within sedimentary rocks, that have not yet been re-assessed by us, south and east of Vista Lake.

Along the northern shore of, and on associated islands within, East Bay, rusty zones rich in sulphide, chert and pelite occur at the northern margin of the metasedimentary rocks where they are in contact with mafic volcanic rocks (Figure 2, locality N). These rocks are traversed by north-trending quartz-sulphide veins that are well-known gold occurrences (Figure 2, locality D).

Along the south shore of King Bay (Robinson and MacLean, this volume), two old mines lie beside an east-trending ironstone-chert unit only a few metres thick (Figure 2, locality M).

Tonalite-Granodiorite Intrusions

Much of the Lewis Lake batholith consists of a complex suite of rocks of various compositions. The batholith commonly consists of coarse-grained biotite and biotite-hornblende tonalite; gabbroic, dioritic and granodioritic variants, net-veined intrusions, granitic pegmatites and aplites also occur. All show varying degrees of mineral alignment to form a foliation and a lineation. These fabrics are especially well developed near the contact with the greenstone belt, where sheeting of the granitoid in the mafic rocks produces rafts and abundant xenoliths.

This suite of rocks was not re-investigated in detail. One traverse was made in order to determine the variation in strain state from the marginal phases to the centre. Sulphide-rich pegmatites (Figure 2, locality G) and a sulphide-bearing felsic-mafic magmatic breccia (Figure 2, locality F) were noted.

Granodiorite-Granite Intrusions, Including Porphyry

At, or near, the contact zone of the Lewis Lake batholith with the Sturgeon Lake greenstone belt, a more evolved suite of granitoid rocks occurs. They contain much potash feldspar, and megacrysts of both quartz and feldspar in a finer grained quartz, biotite, feldspar matrix. These rocks are distinguished from the tonalite-granodiorite suite by their megacryst content, the occurrence of alkali feldspar and their poorly developed mineral foliation. They may be seen at or near the boundary with mafic volcanic rocks near King Bay, North Arm and Rainbow Island, occurring as quartz ± feldspar porphyritic bodies within mafic volcanics, or at mafic-felsic volcanic contacts (Robinson and MacLean, this volume).

Shear zones, swarms of quartz veins and patchy carbonate-chlorite alteration commonly occur associated with the contact between the granitic suite and the mafic volcanic rocks. One example of this is on Rainbow Island (Figure 2), where gold and chalcopyrite are found within carbonate-bearing shear zones and quartz veins (Janes et al. 1990, 1991).

STRUCTURAL GEOLOGY

This project uses structural geology techniques to aid in the interpretation of the relative age and inter-relationships between the volcanic and sedimentary units. To this end, we describe the structural geology in terms of the fabrics exhibited, the strain recorded by the rocks, and the geometry of the units. To some extent, these fabrics are variable within the greenstone belt, so it has been subdivided into regions displaying structural homogeneity. A thorough discussion of these data awaits further analysis.

Stratigraphic Facing in the Greenstone Belt

Most of the volcanic rocks within the Northeast Arm display top indicators demonstrating that these rocks have not been folded on a regional scale, but are tilted, and display a southeast to easterly stratigraphic facing (Figure 2). This set of observations is in accord with recent mapping by Robinson and MacLean (this volume) in the volcanic rocks of the Six Mile Lake area, where stratigraphic facing is consistently to the south. In mafic volcanic rocks, facing directions determined by earlier mappers were confirmed. In kilometre-thick sequences of felsic rocks typically found in the Northeast Arm and in the Six Mile Lake area (Robinson and MacLean, this volume), top directions are consistent. In contrast, stratigraphic facing is locally variable, in Sturgeon Narrows (Figure 2, locality O), within thin units of felsic volcanic rock hundreds of metres thick, and generally within metasedimentary rocks. Zones of complex stratigraphic facing occur especially within East Bay and the northern section of Sturgeon Narrows; some of these areas coincide with field recognition of metre-scale folds, but in East Bay, structural facing changes also appear to coincide with offset across slightly bedding discordant (thrust?) faults. Along the eastern margin of the belt, younging directions are complex and appear to face westward. Despite the change in stratigraphic younging across the belt, we do not infer a major fold within the belt because the thicknesses and stratigraphic character of the oppositely facing sections are very different.

Definition of Sub-areas

Sub-areas have been demarcated on the basis of outlining regions of structural homogeneity. This was both visually determined from regional variability of structural data on the map and from clustering of numerical data on stereograms. Sub-areas therefore tend to show much less variation in the attitudes of structural features than the region as a whole. Four sub-areas have so far been recognized: A: Beckington, B: East Bay, C: Sturgeon Northeast Arm, D: Vanessa-Vista.

Comparison of Sub-areas

The major mineral foliation fabric in the weakly deformed rocks trends generally northward and is steeply dipping. The structural sub-areas differ from each other in orientation of the dominant foliation and lineation, and in the degree of total strain. These are controlled, to a large degree, by the proximity to and orientation of the contact with the tonalite-granodiorite masses that border the greenstone belt (sub-areas A and D). An exception is the East Bay sub-area B, where generally arcuate, east-trending fabrics occur in all rock types, but especially in a complex zone of clastic metasedimentary and felsic metavolcanic rocks occurring between two major mafic metavolcanic units. Rocks in the eastern section of sub-area B display fabrics trending southeast (Figure 2, locality U). The two sub-areas A and D, on the eastern part of the belt, contain rocks more highly deformed than those in the west and central parts of the belt. Rocks in the Northeast Arm, sub-area C, exhibit generally low degrees of strain and consistent fabric orientations.

Structural Chronology

Two structural events have been recognized; the first induced the formation of a schistosity that sub-parallels the original lithological layering; the second is a northeasterly to easterly trending set of folds and associated axial planar fabric.

Much of the area (e.g., sub-area C) displays a weakly developed planar fabric that is sub-parallel to the original stratification (S_0) of the volcanic and sedimentary rocks; we have labelled this fabric S_1. This fabric is strongly developed along the highly strained eastern margin of the greenstone belt in sub-areas A and D; elsewhere it is weak, and commonly difficult to discern.

Overprinting this fabric in sub-areas A, B and C is a variably developed, northeast- to east-northeast-trending planar schistosity S_2; this was also recognized by Trowell (1983a). S_2 parallels the axial surfaces of centimetre– to metre-scale folds that affect both the original stratification and S_1 (Figure 2, localities V and Z). Only rarely is S_2 developed in sub-area D, perhaps because these rocks are coarse–grained, granular and less anisotropic than their lower grade, more miceaceous counterparts in the other sub-areas. Indeed, in the mafic volcanic rocks of the Northeast Arm, these D_2 fabrics are rarely developed except in the schistose tops to mafic flows.

Zones of strong schistosity and lineation development typically occur at the contacts between mafic and felsic volcanic units (Figure 2, localities I and T). These are zones of intense shear in which primary textures and older structural fabrics are virtually or completely superceded by new fabrics. The sheared zones coincide with zones of alteration and veining rich in muscovite, carbonate and chlorite, which may have played a role in focussing the strain. These zones of high strain appear to have been superimposed on earlier deformations. Kinematics on these shears are variable and perhaps complicated by several stages of motion (e.g., Figure 2, locality T). Northeast- to north-northeast-trending shear zones exhibit both west-side-up vertical and sinistral strike-slip kinematics, whereas those with an easterly to east-southeasterly trend are dextral strike-slip structures (Figure 2, localities X and Y).

One major difference distinguished between the northern part of the Sturgeon Lake area, and Savant Lake (Sanborn-Barrie 1991) is that in the latter, the D_2 deformation is much stronger, transposing originally north-trending stratigraphic units into an easterly orientation. In the Sturgeon Lake area, units are not transposed into an easterly trend, the geometrical modification by D_2 is negligible.

Significance of Structures

Despite the fact that most of the rocks within the western part of the greenstone belt are steeply dipping and even slightly overturned, the panels of volcanic and sedimentary rock exhibit generally low strain levels except at greenstone belt margins, and along major lithological contacts. Foliations in the belt and in the batholithic rocks that border the belt are sub-parallel; for this reason we consider that the regional schistosity (S_1) was imposed during or after the emplacement of the tonalite bodies. There is fragmentary evidence of a mineral foliation predating the northerly trending one (S_1) on the eastern edge of the belt.

Relationship of Strain State to Rock Composition and Origin

Rocks containing phyllosilicate minerals such as muscovite and chlorite are coincident with zones of intense shear and fabric development. It is facile, but all too common, to describe the formation of shear zones in terms of structural geometry and the common spatial association of strain and related alteration. Rarely, however, is evidence presented of the time relationships between the two. Original lithological composition and anisotropy, in addition to any alteration that it may have undergone prior to deformation, may have played a key role in determining the location and degree of strain, not vice versa.

MINERALIZATION

A number of different types of mineral occurrence have been briefly investigated to assess their relationship to both lithological and tectonic controls.

Relationship of Mineralization to Tectonic Structures

The mineralization and attendant alteration in the Lyon Lake and Mattabi base metal mines is associated with coarse, proximal to central facies pyroclastic felsic volcanic rocks. Despite recognition of coarse (greater than 1 m clast diameter) volcanics in the area studied, no further alteration or mineralization has been recorded from the remainder of the belt, except for a small region between the Sturgeon and Savant Lake belts, documented by Trowell (1981) and Sanborn-Barrie (1991).

Other types of mineralization in the region are:

1. Contact zones between mafic volcanics and granitoid rocks (Au, Cu); examples include Rainbow Island, the St. Anthony Mine (Figure 2, locality C) and perhaps the two old adits on the south shore of King Bay (Figure 2, locality M).

2. Contact zones between mafic and felsic volcanic rocks (Au, Cu); examples include the "carbonate-breccia"

rock of Trowell (1983b) in the Northeast Arm of Sturgeon Lake (Figure 2, locality H).

3. Vein systems within or closely associated with ironstone units in clastic metasedimentary rocks (Au); examples include old adits at East Bay and perhaps the newly investigated occurrences south and east of Vista Lake.

4. Carbonatized and altered mafic volcanic rocks and associated blue quartz veins at King Bay (Robinson and MacLean, this volume; *see* also Figure 2, locality E). Perhaps coincidentally, 100 m to the north of the mineralized zone is a 1–2 m wide layer of felsic volcanic rocks that has focussed shearing.

CONCLUSIONS

1. Two major stages of deformation developed. D_1 produced fabrics that sub-parallel the original layering; D_2 produced northeasterly trending minor folds and associated schistosity. These two deformations are similar to those in the Savant Lake region to the north.

2. There is strong geological and geophysical correlation between the mafic and felsic volcanic rocks of the Northeast Arm, with those in the Six Mile Lake area.

3. No new alteration zones spatially associated with felsic volcanism were found.

4. Contact zones between granitic rocks and mafic volcanics are commonly sheared and contain Cu-Au mineralization. Flat-lying fabrics west of the St. Anthony Mine, and quartz veins in the neighbourhood of the volcanic-granite contacts, are both typical high-level features characteristically found in association with the roof zones of plutonic bodies.

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8. Project Unit 91–10. Geology of the Rocky Island Lake–Lac Aux Sables Area

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INTRODUCTION

This report presents the preliminary results derived from reconnaissance mapping of a 1200 km², geologically poorly known area of predominantly granitoid rocks situated to the north of the Quirke Syncline north of Elliot Lake in the Mount Lake area (*see* Figure 1). The main objective of this project is to more precisely define the mineral potential of a vast granitoid terrain and secondly to provide a comprehensive petrographic and mineral and litho-chemical data base which could identify possible provenance areas for the uranium ores of the Elliot Lake area.

MINERAL EXPLORATION

There has been extremely little exploration in the map area due to a perceived low mineral potential. The sole record of mineral exploration involved Geophysical Engineering Limited which, in 1975, examined a sulphide occurrence in the extreme northwest corner of Viel Township. The chalcopyrite-pyrite mineralization was evaluated by five diamond-drill holes totalling 306 m and assays for Cu, Au and Ag (Data Inventory Files, Resident Geologist's Office, Sault Ste Marie).

PREVIOUS GEOLOGICAL INVESTIGATION

Despite the voluminous literature on the Elliot Lake uranium ores, there is no systematic study of the vast granitoid terrain situated to the north of the Quirke Syncline. Many workers considered such granitic areas to represent the provenance of the radioactive component of the ores (e.g., Robertson 1976b; Robinson and Spooner 1984; Kissin and Fralick 1991).

Various segments of the map area have been investigated over the past 50 years. Harding (1939) recognized massive pink granite and granite gneiss units in the northern parts of Sagard, Viel and Piche townships, respectively. Sheeran (1952), working in the Lac Aux Sables–Mozhabong Lake area, commented that such rocks were "very uniform in colour and texture." Robertson (1970a, 1970b, 1976a) established the widespread presence of massive red granite and pegmatite basement to the Gowganda Formation conglomerates in Sagard and Poulin townships. Wood (1968, 1975) developed the most detailed division of the granitoid rocks to date in the area and defined eight map units in the northern parts of Viel and Piche townships. Reconnaissance coverage (1:63 000) of granitoid rocks in that portion of the area north of latitude

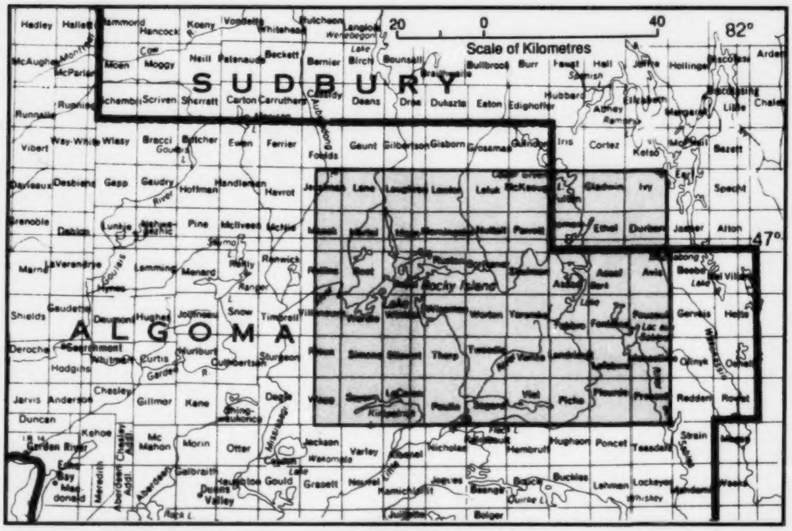

Figure 1. Location map of study area, scale 1:1 584 000.

45°45'N was included in Operation Chapleau (Thurston et al. 1971, 1977). Most of this area was determined to consist of massive, coarse-grained granite and granodiorite; alkali feldspar granite and trondhjemite were deemed to be rare (Thurston et al. 1977).

Several studies near the map area have involved similar granitoid terrain. Rodgers (1962) conducted reconnaissance mapping (1:63 360) in the Biscotasing Lake region, in the northeast corner of the area. Card and Innes (1981) examined granitoid rocks 25 km east of Lac Aux Sables near the Benny greenstone belt. Massive, coarse-grained granite and granodiorite, south of the Benny greenstone belt were considered to form part of the vast Cartier Batholith.

REGIONAL GEOLOGICAL SETTING

The regional investigations of Card (1979) advanced a lithotectonic subdivision of the Wawa and Abitibi subprovinces. The current map area contains two of Card's divisions, the "Algoman gneiss domain" and the "Algoman plutonic domain."

The Algoman gneiss domain constitutes a 10 to 40 km wide zone immediately north and northeast of the Southern Province predominantly consisting of tonalite-granodiorite gneiss, with supracrustal inclusions (Card 1979, p.88–89). Local felsic intrusions of massive and foliated granite, granodiorite and minor syenite and diorite may occur. Within the map area the Algoman gneiss domain is about 10 km in width.

The Algoman plutonic domain lies immediately north of the tonalite-granodiorite gneiss and represents "one of the largest areas of massive felsic plutonic rocks in the southern Superior Province" (Card 1979, p.88). This domain is generally composed of coarse-grained, commonly porphyritic granite, quartz monzonite and subordinate granodiorite emplaced between 2.5 and 2.7 Ga (Card 1979). The Algoman plutonic domain comprises approximately 90% of the study area.

GENERAL GEOLOGY

The map area can be partitioned into three subdivisions, listed in order of increasing relative age: Kindiogami River Batholith, Cartier Batholith and Skunk Lake tonalite-metasedimentary migmatite complex.

Kindiogami River Batholith

This pluton cuts the Algoman gneiss domain in Sagard and Viel townships, and underlies 75 km^2 within the map area. The batholith may extend beyond the map area, possibly underlying much of the Huronian Supergroup between Ompa Lake and the confluence of the Kindiogami and Little White rivers as similar red granites occur in Raimbault and Hembruff townships (Wood 1975).

Most exposures of the batholith are simple and contain only one or two mappable granitic units. The most prevalent rock type is massive, generally unrecrystallized, equigranular biotite granite characterized by deep pink to brick orange weathered surfaces. The latter colouration relates to pervasive hematization of potassium feldspar and plagioclase mainly along joint surfaces and narrow brittle fault surfaces. Notable petrographic features include oscillatory zoned plagioclase and sporadic, quartz-lined miarolitic cavities both indicating a high emplacement level for the batholith, either upper mesozonal or lower epizonal. Medium- and coarse-grain sizes are typical as is a gradation into small, irregular masses of consanguineous potassic pegmatite. Discrete veins of identical pegmatite are also common and may reflect a late migration of residual fluid/melt along fractures in the previously crystallized parent granitic melt.

Compositional gradation into alkali—feldspar granite, quartz syenite and syenite have also been recognized, albeit in only a few scattered localities such as near Beavertail Lake, along the Little White River in north-central Sagard Township and 1.2 km east of River Lake.

Commonly, textural variation is expressed by a gradation from fine- to medium- to coarse-grain sizes on an outcrop scale and also by the conspicuous presence of an earlier porphyritic and rarely glomeroporphyritic biotite granite unit, e.g., immediately east of Block's Pond in Sagard and Viel townships.

Characteristic of the unit is a ubiquitous inclusion population that is variable in composition, abundance (less than 1 to 20%) and size. These inclusions are in order of abundance: clastic metasedimentary rocks and derived migmatite, foliated amphibolite, tonalite, granodiorite, diorite and rare phlogopite-actinolite meta-ultramafic and metagabbroic rocks. Migmatitic metasedimentary inclusions in several areas have dimensions that exceed outcrop scale. Robertson (1976a) mapped several large inclusions (up to 0.5 km^2 in the Stewleen Lake area and in Poulin Township).

The ubiquitous, potassic, pegmatite segregations generally contain accessory levels of peraluminous minerals such as garnet, biotite and muscovite. The latter mineral is much more restricted than biotite and is essentially confined to pegmatitic phases within the eastern part of the batholith as observed along the Skunk Creek road. Here, silver muscovite books up to 2.5 cm diameter abundantly occur in milky quartz-rich pegmatite core zones also populated by blocky microcline perthite crystals up to 6 by 15 cm. To date, no exotic minerals enriched in rare-elements (Ba, Cs, Li, Nb, Ta, Rb and Sr) have been recognized.

The two dominant granite clast types in the overlying basal conglomerate of the Gowganda Formation greatly resemble equigranular and porphyritic granite units of the Kindiogami River Batholith. The prevalent milky quartz clasts in the Gowganda Formation may in fact have been derived from the quartz-rich core segregations developed within the ubiquitous potassic pegmatites occurring within the Kindiogami River Batholith.

Cartier Batholith

Granitoid rocks within this, the largest map unit, comprise about 90% of the study area and are tentatively correlated with the Cartier Batholith situated 25 km to the east (Card and Innes 1981). The batholith may represent amalgamation of several intrusive centres to produce the vast area underlaid by the Cartier Batholith. A significant 23 by 57 km, elongate, east-trending airborne radiometric anomaly is associated with the batholith, defined by equivalent uranium values exceeding 2 ppm and achieving a maximum of 3.6 ppm (GSC 1975; Charbonneau 1982).

Contact relations with the Kindiogami River Batholith to the south were not satisfactorily resolved, however, the Cartier Batholith is likely older as dikes similar to the fine- to medium-grained, deep pink granite of the Kindiogami River Batholith are widespread particularly in the southern part of the Cartier Batholith. Host rocks of the batholith along its northern contact locally consist of foliated and gneissic tonalite as in Shulman Township.

The batholith dominantly consists of massive, light pink to pink-grey, biotite granite and granodiorite in which the vast majority of exposures are composed of a few units. Colour index is normally less than 10. Biotite is usually the only mafic mineral. In the minor syenitic units, described below, colour index may rise to 25. Mafic minerals (biotite and/or aphanitic, dark green-black chlorite aggregates) are interstial to the feldspars. Hornblende appears locally in some porphyritic granites as at the northwestern fringes of the map area in central Scriverner and Shulman townships.

A prime characteristic of the Cartier Batholith rocks is the presence of a coarse-grained, seriate, hypidiomorphic-granular texture marked by a low abundance (less than 5%) of isolate, 10 to 20 cm megacrysts of blocky to irregular potassium feldspar and lesser ovoid "blobs" of grey to milky quartz . Such megacrysts are reminiscent of pegmatitic granites described by Cerny and Meintzer (1988). At many localities, such as near Esker Lake in Yaremko Township, a small portion of the megacryst population may consist of a graphic intergrowth of potassium feldspar and quartz. Porphyritic textures are also ubiquitous but subordinate to the blocky megacrystic texture. This textural variant is generally marked by 5 to 20% euhedral, tabular potassium feldspar phenocrysts typically 1 by 3 cm in size, immersed in a matrix of plagioclase-quartz-biotite.

Segregations of potassic pegmatite form a widespread, albeit volumetrically minor, unit of the batholith. It is generally gradational into its granite or granodiorite host and is barren of exotic minerals characteristic of the rare-element pegmatite class (Cerny 1989a, 1991a, 1991b). Biotite, specularite and rare muscovite represent the sole accessory minerals. However, some pegmatites clearly have attributes of the "miarolitic class" of Cerny (1989a, 1991a) as impressive miarolitic cavities associated with 0.5 to 0.6 m thick potassic pegmatite layers hosted in coarse-grained, holo-leucocratic red granite were encountered on Bark Lake in east-central Assad Township. Irregular vugs up to 5 by 27 cm are lined with euhedral milky quartz and lesser chalcedony and cristobalite. Chlorite-rich syenite pods near these miarolitic layers also contain tubular vugs 13 by 18 by greater than 80 cm in size.

Additional subordinate rock types include syenite, monzonite, quartz syenite and quartz monzonite. These coarse-grained rocks are ubiquitous but rarely compose more than 5% of a given exposure, occurring as metre-size pods and indistinct layers gradational into the granite host. Only rarely do these compositions achieve dominance at the outcrop scale as at Moon Lake in Monestime Township. Miarolitic cavities, typically lined with euhedral milky quartz, commonly occur in the syenitic units and vary in size from 1 to 5 cm. The syenitic rocks may represent the chemically most fractionated members of the Cartier Batholith, given the common occurrence of miarolitic cavities lined with quartz crystals, lending strong testimony to the former presence of a silica-rich vapour phase, commonly a product of advanced differentiation of granite-pegmatite systems (Jahns 1982; London 1986). Considerably rarer rock types include ochre potassium feldspar-plagioclase porphyry and purple-red syenite forming less than 2 m wide dikes cutting the main unit of the Cartier Batholith in north-central Tweedle and south-central Worton townships. The genetic relationship of these dikes with the batholith is not clearly understood at the moment.

Layering, defined by increase of potassium feldspar, biotite and magnetite coupled with a diminishment of quartz, is locally evident particularly in the large area of clean exposure situated just east of the north end of the Portelance road in Shulman Township. Here, 15 to 25 cm thick layers possibly of cumulate origin, grade into a porphyritic granite host.

Inclusions are typically found only near the southern contact. These inclusions consist of metasedimentary migmatite, foliated amphibolite, massive and weakly foliated tonalite, diorite and syenodiorite. In Shulman Township, an inclusion of highly strained, intermediate pyroclastic breccia provides evidence of ductile deformation of supracrustal units prior to emplacement of the Cartier Batholith. Furthermore, in the same area blocks of massive, medium-grained tonalite have been incipiently to pervasively epidotized before incorporation into the batholith.

Skunk Lake Tonalite-Metasedimentary Migmatite Complex

The third map unit is the least extensive yet the most complex of any in the area. This southeast-striking, 5 by greater than 12 km zone consists of massive and foliated tonalitic rocks interbanded with lesser metasedimentary migmatite and inclusion-rich S-type granite. It is mainly wedged between the Kindiogami

River Batholith on the west and the Cartier Batholith along its northwestern and northeastern periphery. The southern limit is currently undefined; however, it may be marked by the Flack Lake Fault in Piche Township (Wood 1975).

A significant portion of this complex consists of a peculiar *hornblende-biotite tonalite that commonly exhibits* a wide range in composition at the outcrop scale with metre-sized, gradational patches of granodiorite, granite, quartz syenite, syenite and syenodiorite. This massive to weakly foliated, medium- to coarse-grained, white to light pink weathering, hypidiomorphic-granular rock is characterized by 2 mm to 7 cm euhedral plagioclase and a heterogeneity imparted by lensoidal to irregular segregations of coarse (up to 5 cm diametre), anhedral, bright pink potassium feldspar. Syenitic segregations commonly form discontinous, 1 to 5 cm thick halos around inclusions of amphibolite and hornblendite that exhibit a pre-existing planar deformation fabric. Hornblende syenodiorite tends to occur around extensively assimilated mafic inclusions. Inclusions of gneissic tonalite are rare.

Metasedimentary migmatite includes widespread metatexite. This highly deformed rock typically consists of 10 to 20%, white, medium- to coarse-grained granite leucosome interbanded with fine-grained metawacke and much scarcer biotite-rich metapelite mesosome. Several exposures near Rosemarie Lake reveal later sills of massive to weakly foliated tonalite described above. Also notable in this area are bright pink potassium feldspar porphyroblasts in the tonalite and more rarely in the metawacke mesosome.

Small masses of S-type granite are spatially linked with the zones of metatexite. These are generally less than 1 km^2 in size and typically with abundant (20 to 50%) inclusions of metawacke and subordinate metapelite and foliated to gneissic amphibolite. Hornblendite, diorite and anorthositic gabbro are considerably rarer.

The S-type granite is characterized by white potassium feldspar and ubiquitous clumps and schlieren of coarse, biotite-rich masses perhaps representing a residue after extensive anatexis of a metasedimentary precursor. Furthermore, plagioclase and potassium feldspar tend to be euhedral through a considerable grain size range (2 mm to 3 cm). Patches of white potassic pegmatite are common. Peraluminous accessory minerals such as garnet, cordierite, tourmaline, muscovite and sillimanite are, however, rare in these S-type granites . This is is contrast to similar migmatites and derived granites from the English River Subprovince (Breaks et al. 1978) or the Quetico Subprovince (Williams, in press). A single occurrence of garnet and cordierite-quartz intergrowths was recognized in metatexite leucosome near Rosemarie Lake. At Richie Falls in Monestime Township, garnet, muscovite and chlorite-rich pseudomorphs possibly after cordierite sparsely occur in medium- to coarse-grained granite and lesser quartz syenite. This single exposure of S-type granitic rocks, however, appears to be isolated within the Cartier Batholith and its relationship to similar rocks in the Skunk Lake Complex is uncertain.

The S-type granites are postdated by prevalent dikes and small stocks of medium-grained, equigranular, biotite granite gradational pegmatite possibly linked with the Kindiogami River Batholith. Much rarer tonalitic units also intrude the S-type granites: massive to foliated hornblende-biotite and biotite tonalite identical to the main unit in the Skunk Lake Complex described above and undeformed biotite trondhjemite dikes. Examples of both occur in the Rosemarie Lake area.

STRUCTURAL GEOLOGY

The map area is dominated by massive, undeformed, post-tectonic granitoid rocks which were emplaced between 2500 and 2700 Ma (Card 1979) and subsequent to the Kenoran orogenic event. However, brittle deformation structures are widespread as variably penetrative fractures and faults and may, in large part, have been induced by the Penokean orogeny. The faults generally are narrow, less than 5 cm wide zones, commonly filled with fine-grained chlorite and milky quartz and rarely with epidote, hematite, calcite and sericite. Zones of fault breccia containing host-rock fragments of variable size are commonly cemented by pink calcite and dark green to black chlorite and are rendered conspicuous by brick orange hematite staining. Larger faults were also delineated in the area, the most important being the West Ritchie Lake Fault. This northeasterly-striking, sinistral, 30 m wide fault forms a prominent valley traceable for 13 km in Sagard, Viel and Vance townships. It is marked by strong development of quartz veining, a wide variety of rock units and pockets of fault breccia. Lithologies overprinted by this fault include metasedimentary migmatite, the predominant equigranular and porphyritic units of the Kindiogami River Batholith and several units of the Gowganda Formation (purple siltstone and sandstone, matrix supported polymictic conglomerate and orange-red arkose).

Ductile deformation is essentially restricted to the Skunk Lake Complex. Two periods of folding are commonly observed in metatexitic migmatite. Such folds developed subsequent to a high grade metamorphic event responsible for the anatectic segregation of leucosome layers. D_1 produced east- to southeast-trending tight to isoclinal Z-folds with axial planes coplanar with the enclosing schistocity. This event was overprinted by the dominant D_2 deformation which produced open Z-folds, also east-trending, with widely variable plunges (10 to 74°) and a well-developed biotite lineation. Relationship of these ductile deformation events with that responsible for development of gneissosity in the tonalite inclusions in the widespread massive to foliated hornblende-biotite tonalite unit in the complex is uncertain.

ECONOMIC GEOLOGY

Exploration targets within the Rocky Island Lake–Lac Aux Sables area are restricted to only a few industrial mineral possibilities:

1. dimension and decorative stone, and
2. specular hematite as paint filler.

Sulfide mineralization is practically absent and restricted to some major fault zones.

Dimension and Decorative Stone Potential

The best economic potential of the area lies in these commodities. Massive granitic rocks suitable for applications as building facings and granite pavers are commonplace in the Cartier Batholith. The areas recommended for exploration resulting from this mapping are the Shoepack–Bark lakes and Lac Aux Sables–Pouporre lakes areas. Fresh, unhematized parts of the Cartier Batholith having an attractive light pink and grey pink colouration, a favourable flat-lying joint pattern with a 1 to 3 m spacing and a grain-size uniformity were commonly encountered here.

Exploration for decorative and dimension stone in the map area should avoid areas having the following characteristics:

1. intense jointing patterns,
2. non-uniform grain size caused, for example, by megacrysts of potassium feldspar and irregular masses of quartz,
3. masses of potassic pegmatite,
4. presence of metamict accessory minerals such as titanite and allanite, and
5. presence of patchy hematization zones.

Decorative stone possibilities are widespread amongst the granitoids of the Cartier and Kindiogami River batholiths which exhibit a considerable array of colours and textures. The author has a broad collection of polished material from these plutons which best illustrates this potential and is available for inspection in the Sudbury Advance Office of the Ontario Geological Survey.

Rare-Element Pegmatite Potential

The rare-element pegmatite potential of the area will be assessed by analysis (Ba, Cs, Ga, Li, Rb and Sr) of blocky potassium feldspars sampled from potassic pegmatites associated with the Kindiogami River and Cartier batholiths and following the evaluation parameters of Cerny (1989b).

Specular Hematite

Specularite is ubiquitous in the Cartier and Kindiogami River batholiths and its distribution extends eastwards to the Sault Ste. Marie area (Personal communication, G. Bennett, Resident Geologist, Ontario Geological Survey, Sault Ste. Marie). Hematite occurs in a number of settings which suggest an extended period of deposition which predates and postdates the deposition of the Gowganda Formation:

1. as fracture coatings,
2. in brittle fault zones,
3. disseminations in coarse-grained granite,
4. in quartz-rich core zones of potassic pegmatites, and
5. as disseminations and vug fillings in quartz veins crosscutting the Gowganda Formation.

In view of the use of micaceous specularite as a paint filler and pigment (G. Bennett, personal communication, 1991) the area should be routinely prospected for potentially mineable vein deposits of this variety of specularite.

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9. Project Unit 90–20. Geology of the Whiskey Lake Greenstone Belt, Districts of Algoma and Sudbury

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INTRODUCTION

Investigations of the Archean rocks near Elliot Lake began in 1990 to expand the geological data base in the area and to stimulate mineral exploration following the recent closures of uranium mines in the region. The geological examination of the Archean Whiskey Lake greenstone belt was completed during this second field season of mapping.

The Whiskey Lake greenstone belt is a 30 km long, arcuate belt of Archean metavolcanic and metasedimentary rocks centered approximately 25 km east of Elliot Lake. The area is bounded by latitudes 46°19' N to 46°26' N and longitudes 82°14' to 82°35' W. Proterozoic sedimentary rocks of the Huronian Supergroup occur to the north and gabbroic and granitoid rocks of Proterozoic and Archean age occur to the east and south of the belt (Robertson 1961, 1962, 1977).

Jensen (1990) mapped the western portion of the area at a scale of 1:15 000. During the 1991 field season the eastern portion of the belt, which totalled about 85 km², was mapped at a scale of 1:15 000. This area included the eastern portion of Gaiashk Township and most of Gerow Township (*see* Figure 1). Portions of this area had been previously mapped by Robertson (1962) and McCrank et al. (1982).

Coincident with this mapping program, lithogeochemical studies of the Archean rocks of the Whiskey Lake belt are being conducted by the Geology Department of Laurentian University (Byron and Whitehead, this volume).

The southern part of Gaiashk and Gerow townships can be accessed by a powerline road which extends westward from Highway 553, approximately 25 km north of the town of Massey. The northern portion of the area is accessible from Whiskey and Folson lakes and by all terrain vehicle and walking trails in the area.

MINERAL EXPLORATION

The search for uranium deposits near the base of the Proterozoic, sedimentary Matinenda Formation has been the focus of past exploration in the Elliot Lake area. Most of the work in Gaiashk and Gerow townships has been summarized by Robertson (1962). Limited exploration for base metals in the Archean rocks was carried out between 1950 and 1970 (Robertson 1962, 1977). To date, no known exploration programs for precious metals have been conducted in the map area.

The following information has been summarized from

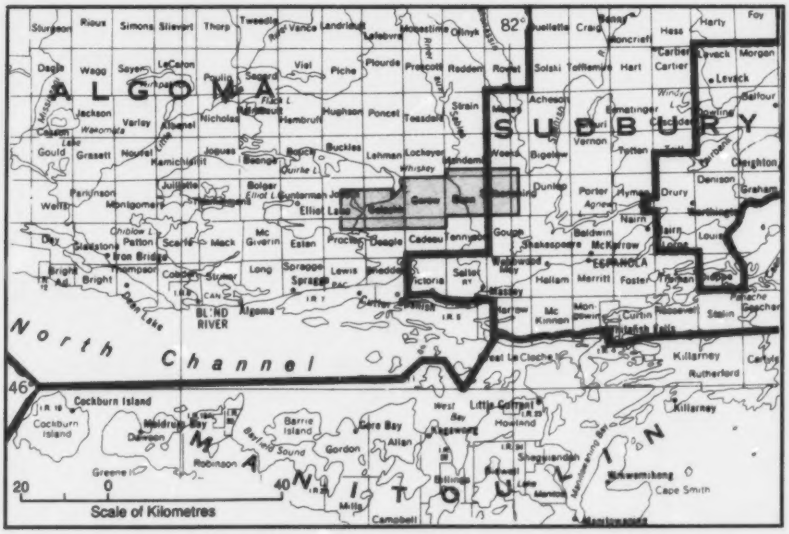

Figure 1. Location map of the Whiskey Lake greenstone belt area, scale 1:1 584 000.

the files of the Assessment Files Research office, Ontario Geological Survey, Toronto.

In 1953 and 1954, Algom Uranium Mines Limited, British Columbia Explorers Limited, Grand Chibougamau Mines Limited and Chubb Featherstone conducted diamond drill programs to the east of Whiskey Lake to test for uranium mineralization hosted by Proterozoic quartzites of the Matinenda Formation. No significant values were encountered.

In 1954, Teasdale Uranium Mines Limited carried out a diamond drill program comprising four shallow holes to assess a quartz vein hosted by diabase on Campbell Island in Whiskey Lake. Only local concentrations of less than 0.5% galena and chalcopyrite were encountered.

In 1955, March Minerals Limited conducted a ground magnetometer and scintillometer survey in east-central Gaiashk and west-central Gerow townships which located three high magnetic areas. Two of the zones were examined by 1708 feet (519 m) of diamond drilling in 1956. Mafic volcanic and gabbroic intrusive rocks were intersected, with minor, disseminated pyrite and chalcopyrite found locally in the gabbros.

In 1956, El Pen-Rey Oil and Mines Limited examined copper-nickel occurrences in the East Bull Lake gabbros along the eastern boundary of Gerow Township with 14 diamond-drill holes totalling 7819 feet (2370 m). Several of these holes intersected sparse chalcopyrite-pyrrhotite mineralization generally associated with fracture zones.

In 1978, Panel Consolidated Uranium Mines Limited drilled two diamond-drill holes totalling 1965 feet (600 m) near the southeast shore of Whiskey Lake in Gaiashk Township to test for uranium mineralization. No assays results were reported.

GENERAL GEOLOGY

The Whiskey Lake greenstone belt of Archean supracrustal rocks forms an easterly trending, 10 km by 30 km, synclinal greenstone belt that extends from about 6 km east of Elliot Lake to near the eastern boundary of Gerow Township. Younger granitoid rocks of Archean age bound the belt to the south and east, and gabbroic and granitoid rocks of Archean to Proterozoic age lie to the northeast. A synclinal sequence (Quirke Syncline) composed of Proterozoic volcanic and sedimentary rocks unconformably overlies the Archean sequence to the north.

The metamorphosed Archean supracrustal rocks within the 1991 map area (*see* Figure 2) consist of tholeiitic basalt flows intercalated with fine-grained, calc-alkalic, intermediate to felsic tuffs. Sedimentary rocks were not found in the Archean sequence. Regional greenschist to lower amphibolite facies metamorphism has affected the Archean supracrustal rocks.

Archean gabbro stocks, sills and dikes intrude the supracrustal sequence across the southern portion of the map area. These lithologies in turn are cut by the Archean granitoid rocks. The dominant and oldest granitoids are massive to gneissic tonalites. These were intruded by granodiorite and quartz monzonite plugs and dikes.

The Parisien Lake Syenite, which occurs as a large stock, intrudes into the eastern end of the Archean sequence in Gerow Township.

Medium- to coarse-grained gabbros of the East Bull Lake intrusion form most of the northern boundary of the Archean supracrustal rocks in the area.

A variety of late Archean or Proterozoic dikes intrude the map area generally with a preferred east-southeast to southeast trend. Nipissing gabbro and diabase plutons of Proterozoic age intruded into the Archean and Proterozoic sequence to the east of Whiskey Lake.

Proterozoic quartzites of the Huronian Matinenda Formation lie unconformably on the Archean supracrustals along the southeast shore of Whiskey Lake. Detailed descriptions of the Huronian Supergroup are given by Robertson (1962).

The development of fine-grained biotite and chlorite is a common product of contact metamorphism in the metavolcanic rocks near the Archean granitoid intrusions. Weak contact metamorphism is also apparent locally in the metavolcanic rocks near some of the mafic intrusive bodies.

Alteration of the Archean rocks, usually associated with shear zones, includes silicification, carbonatization, chloritization and sulfidization.

Several deformational events have affected the metavolcanic rocks. Initial syndepositional folding and tilting was followed by further folding and faulting related to the various phases of granitoid and gabbroic intrusions. This has resulted in the formation of a homoclinal, south facing, steeply dipping and generally overturned sequence which forms the northeast limb of an Archean syncline. The formation of the easterly trending Quirke Syncline in the north part of the map area during the Penokean Orogeny resulted in the folding and faulting of the Huronian sedimentary rocks and the Archean rocks in the vicinity.

The metavolcanic rocks display a strong schistosity. The Archean gabbros and to a lesser degree the gneissic tonalites also display a penetrative foliation.

Table 1 represents the perceived general sequence of geological events in the area.

The greatest, and as yet untested mineral potential within the eastern portion of the greenstone belt is for the occurrence of structurally controlled gold mineralization related to the intensely altered shear zones, especially those interpreted to be Archean in age.

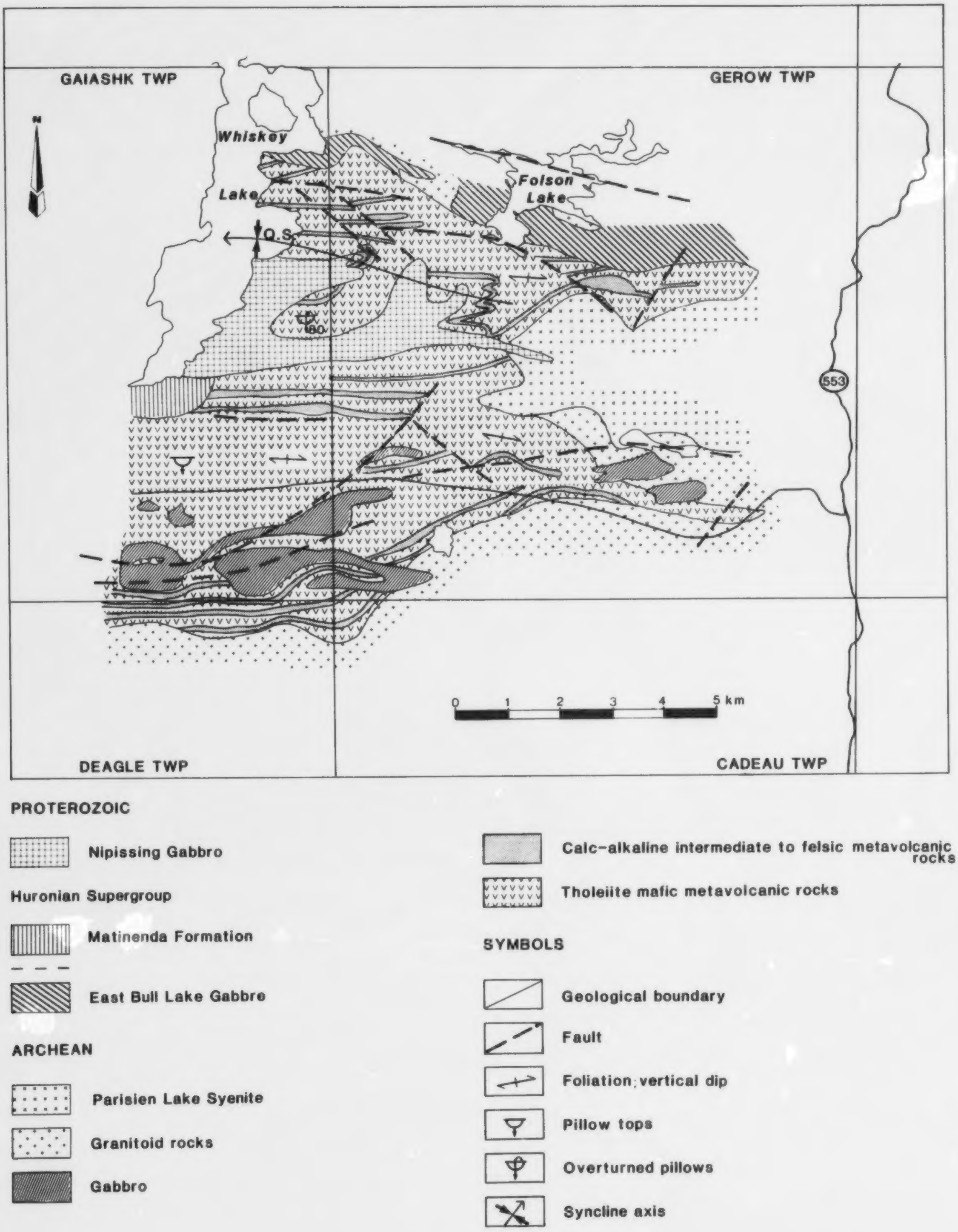
GAIASHK TWP
GEROW TWP
DEAGLE TWP
CADEAU TWP
N
Whiskey Lake
Folson Lake
O.S.
60
553
0 1 2 3 4 5 km
PROTEROZOIC
Nipissing Gabbro
Huronian Supergroup
Matinenda Formation
East Bull Lake Gabbro
ARCHEAN
Parisien Lake Syenite
Granitoid rocks
Gabbro
Calc-alkaline intermediate to felsic metavolcanic rocks
Tholeiite mafic metavolcanic rocks
SYMBOLS
Geological boundary
Fault
Foliation; vertical dip
Pillow tops
Overturned pillows
Syncline axis

Figure 2. General geology of the eastern portion of the Whiskey Lake greenstone belt.

Table 1. Sequence of geological events in the map area

TIME	ROCK UNIT	GEOLOGICAL EVENT
Proterozoic	Amphibole diabase, quartz - feldspar porphyritic tonalite, gabbro, olivine diabase and lamprophyre dikes	
		SE-trending faults and shears
		Quirke Syncline development
		ESE-SE trending shears
	Nipissing gabbros	Local folding
	Huronian sedimentary rocks	
	East Bull Lake gabbros	Local folding
Archean		NW-trending shears
		NE-trending sinistral shears
	Parisien Lake Syenite	Local folding
	Massive granitoids - granodiorite to granite	Local folding
	Foliated tonalite	Development of a gneissic fabric; local folding
		Greenschist to lower amphibolite facies regional metamorphism; formation of syncline, penetrative foliation and regional E-ENE trending, dextral shears
	Tholeiite basalt flows and calc-alkaline intermediate-felsic tuffs; subvolcanic(?) gabbros	

ARCHEAN METAVOLCANIC ROCKS

The metavolcanic rocks of the map area are composed of interlayered tholeiitic and calc-alkalic suites of rocks of the same age. The tholeiitic suite comprises the largest volume of metavolcanic rocks in the region and consists of wide (>200 m), laterally extensive units of fine-grained, massive to pillowed basalt flows with local flow-top and pillow breccia. Single flows are often on the order of 15 m in thickness and range upward from a massive base with a diabasic texture to pillows topped by flow breccia. Both Mg-rich and Fe-rich tholeiitic basalt are present in the area with Mg-rich basalts as the most common.

The calc-alkalic rock suite consists of generally narrow (<100 m) horizons of fine-grained, intermediate to felsic tuffs and rare lapilli tuffs. The tuffs may be distal deposits from the Kings Lake volcanic center, which lies approximately 15 km west of the map area within the Whiskey Lake greenstone belt (Jensen, 1990). Narrow, bedded chert horizons are occasionally found with the tuff horizons, generally at the tops of the units.

ARCHEAN GABBROIC ROCKS

A series of Archean gabbro stocks, dikes and sills intrude the metavolcanic sequence across the south end of the map area.

The gabbros commonly display a penetrative foliation, have been subjected to the Archean regional metamorphism and contain xenoliths of the metavolcanic rocks.

A concentration of large gabbroic intrusive bodies occurs in the southeast corner of Gaiashk Township and southwest corner of Gerow Township. These intrusions are proximal to the thickest accumulation of basalts in the greenstone belt, appear to be very similar in composition to the basalts and may represent a subvolcanic intrusive center to the tholeiitic volcanism.

ARCHEAN GRANITOID ROCKS

A granitic terrain bordering the metavolcanic rocks to the north (east of Whiskey Lake) and also to the south transects the volcanic foliation. The granitoids intrude the Archean metavolcanic rocks and gabbros, and contain xenoliths of these rocks. Intrusive relationships are especially evident in the far southeast corner of the map area where the Archean metavolcanic rocks and gabbros are pinched out by the granitoids. In this area the development of a gneissic to migmatitic fabric is evident with common assimilation features, such as partial melting of the volcanic rocks and the presence of numerous ductilely deformed metavolcanic xenoliths in the granitic rocks.

Several granitoid phases are present in the area, the oldest being a grey to light pink gneissic tonalite. This was intruded by massive, medium-grained, pink tonalite to granodiorite. A medium- to coarse-grained, massive, red quartz monzonite to granite is the youngest, quartz-rich granitoid phase.

The Parisien Lake Syenite occurs as a large stock of medium- to coarse-grained, pink, equigranular to porphyritic syenite which separates the eastern portion of the greenstone belt into two lobes (*see* Figure 2). It cuts the Archean volcanic rocks, gabbros and granitoids and has been dated at 2655 Ma by the U-Pb radiometric method (Krogh et al. 1984). A very similar appearing syenite intrudes the Archean granitic rocks and the East Bull Lake gabbros as small plugs and dikes at the north end of the metavolcanic belt to the west and east of Folson Lake.

LATE ARCHEAN TO PROTEROZOIC INTRUSIVE ROCKS

The East Bull Lake gabbro-anorthosite intrusion borders the metavolcanic rocks in the map area to the north and northeast. It consists of massive, equigranular, medium- to coarse-grained gabbro and anorthositic gabbro which has been age dated at 2480 Ma (McCrank et al. 1989). Peck and James (this volume) offer a detailed description of this intrusion.

A number of large stocks and dikes of Proterozoic Nipissing gabbros intrude the Whiskey Lake greenstone belt to the east of Whiskey Lake. The gabbros are generally medium-grained and comprise melanocratic to leucocratic varieties. The Nipissing gabbro bears intrusive relationships to all of the major rock types including the Huronian sedimentary rocks.

A variety of late dikes intrude the sequence, generally along a trend of 100° to 130°, which is parallel to subparallel to the regional foliation. In decreasing order of abundance these include medium-grained gabbro, plagioclase porphyritic gabbro, fine-grained gabbro, amphibole diabase, quartz-feldspar porphyritic tonalite and felsite. The gabbro dikes may be related to the Nipissing intrusions.

Proterozoic lamprophyre dikes, and olivine diabase dikes of the Sudbury swarm were occasionally found in the area and may be the youngest intrusions to cut the sequence.

HURONIAN SEDIMENTARY ROCKS

Matinenda Formation sedimentary rocks of the Huronian Supergroup were mapped to the south and southeast of Whiskey Lake. The rocks consisted of thickly bedded orthoquartzites and feldspathic quartzites with an easterly strike and shallow dips of 10° to 30° to the north. The Matinenda Formation has an unconformable contact with the underlying Archean metavolcanic and intrusive rocks.

STRUCTURAL GEOLOGY

Structural deformation of the Archean supracrustal rocks occurred as a number of phases preceding, during and following the emplacement of the various granitoid and gabbroic intrusions.

The initial deformation event involved the development of a bedding parallel, steeply dipping, penetrative foliation in the metavolcanic rocks and to a progressively less degree in the Archean gabbros and gneissic tonalites.

A syncline was developed during this time which affected the entire Whiskey Lake greenstone belt. The southeast-trending axis was outlined to the west by Jensen (1990). The supracrustal rocks of the eastern portion of the belt lie on the north limb of the Archean fold. Pillow top facing directions display a consistent, steeply dipping direction to the south. The penetrative foliation may have developed as axial planar cleavage during this folding event. The gneissic fabric in the tonalites may have developed during the waning stages of this event.

Large, dextral, strike-slip shear zones trend 70° to 90° through the southern part of the map area, continuing from the region to the west. As indicated by Jensen (1990), these shear zones probably formed during the early folding event and were subsequently modified by later deformation.

Following the intrusion of the granitoid rocks to the south and north of the greenstone belt and the Parisien Lake Syenite to the east, a series of northeast-trending, subvertical faults with sinistral, strike-slip offsets were developed in the area. These faults were also prevalent to the west (Jensen 1990). Intrusive rock-volcanic rock contacts as well as Archean gabbro and metavolcanic units were offset by the faults.

A number of northwest-trending faults are evident in the region, particularly in the northern portion. A sinistral, strike-slip movement was inferred for one fault as evidenced by offsets of volcanic units.

A series of east-southeast to southeast trending shear zones extend through the northern edge of the map area and appear through the crosscutting relationships to be late, probably Proterozoic faults.

The various major intrusions all created local deformation, notably folding of the volcanic rocks.

The axis of the Proterozoic Quirke Syncline trends easterly through a portion of the northern map area, folding the Archean stratigraphy into broad open folds and locally tight isoclinal folds. A westward plunge is inferred for the Quirke Syncline. The folding did not impart a secondary axial planar foliation to the rocks but may have been responsible for some of the late shear zone development.

As in the area to the west (Jensen 1990), the last structural event was the formation of east-southeast-trending faults which offset both Huronian and Archean stratigraphy. These faults are commonly filled by a variety of late dikes.

ECONOMIC GEOLOGY

The mineral potential of the Archean Whiskey Lake greenstone belt was largely unknown due to the lack of exploration in the area. Jensen (1990) has outlined the potential for the western portion of the belt. The eastern portion of the belt has a varied geological environment suitable for hosting a number of precious and base metal mineralization types.

1. Good potential exists for the occurrence of structurally controlled gold deposits associated with a variety of fault zones, particularly those believed to be Archean in age. These include the large, 70° to 90° trending shear zones and the later northeast- and northwest-trending shear zones. Many of these faults exhibit wide (>50 m) areas of sheared rock with associated silicification, carbonatization and chloritization which can be traced in some localities for several hundred meters. Pyrite can be found in concentrations of up to 10% locally and arsenopyrite and chalcopyrite have been rarely observed. Quartz veining is also prevalent locally along these fault zones.

2. Distal, fine-grained tuffs of intermediate to felsic composition and rare, bedded chert offer some potential as the host environment for volcanogenic massive sulphide deposits. Minor (1-2%), disseminated pyrite is found with the tuffs and cherts in certain localities.

3. The various mafic intrusives in the area have the potential to host Ni-Cu massive sulphide and platinoid-group mineralization. The East Bull Lake gabbroic complex, which borders the volcanic sequence to the northeast, probably offers the best potential. It hosts a number of Ni-Cu and platinoid occurrences to the east of the map area. The mineral potential of the East Bull Lake gabbros is currently being evaluated by Peck and James (this volume).

4. The base of the Matinenda Formation in the area should be examined for horizons with concentrations of detrital sulphides which could host paleoplacer concentrations of gold mineralization.

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10. Project Unit 90–20. Geology of the Ompa Lake Greenstone Belt, District of Algoma

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INTRODUCTION

Investigations of the Archean rocks near Elliot Lake were initiated in 1990 to expand the geological data base in the area and to stimulate mineral exploration following the recent closures of mines in the region. The Whiskey Lake greenstone belt to the east of Elliot Lake was the first to be mapped in the region (Jensen 1990; Rogers, this volume). Geological mapping of the Archean Ompa Lake greenstone belt was initiated during the 1991 field season.

The Ompa Lake greenstone belt is a 30 km long, linear belt of Archean metavolcanic and metasedimentary rocks lying approximately 20 km north of Elliot Lake. The area is bounded by latitudes 46°32'N to 46°36' N and longitudes 82°26'W to 82°44' W.

The present mapping program is a reassessment of areas that have been previously mapped by Robertson (1977) and Wood (1975). The Ompa Lake greenstone belt comprises portions of Raimbault, Hembruff, Hughson and Poncet townships. During the 1991 field season the western portion of the greenstone belt, which included Raimbault Township and the western part of Hembruff Township, an area of about 36 square km, was mapped at a scale of 1:15 000 (*see* Figure 1).

Coincident with this mapping program, lithogeochemical studies of the Archean rocks of the Ompa Lake belt are being conducted by the Geology Department of Laurentian University (Byron and Whitehead, this volume).

Highway 639 passes northward through the eastern end of Raimbault Township. Boat access from Flack Lake and an all terrain vehicle trail to Samreid Lake provide access to the western end of the belt. The western portion of Hembruff Township is accessible from Semiwite and Ompa Lakes.

MINERAL EXPLORATION

The search for uranium deposits near the base of the Proterozoic, sedimentary Matinenda Formation has been the focus for past exploration in the Elliot Lake area. Very limited exploration for base metals in the Ompa Lake belt has been carried out, mainly in Raimbault Township. To date, no known exploration programs for precious metals have been conducted in the map area.

The following information has been summarized from the files of the Assessment Files Research office, Ontario Geological Survey, Toronto.

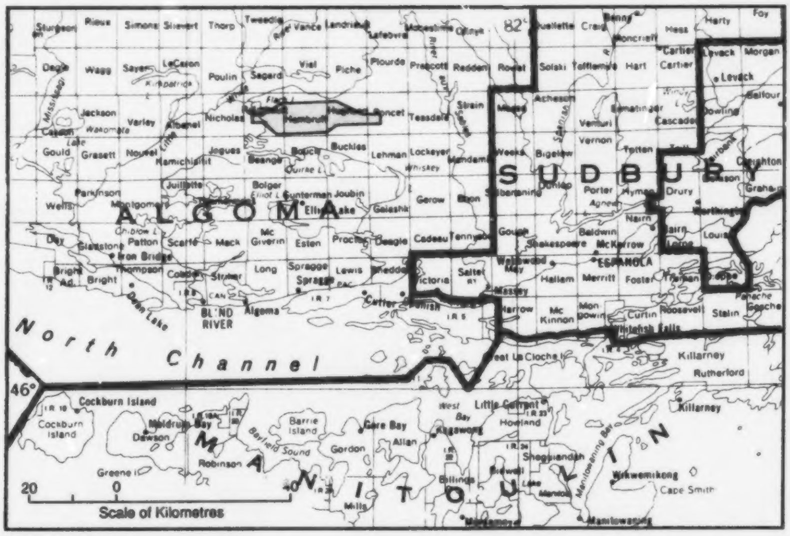

Figure 1. Location map of the Ompa Lake greenstone belt area, scale 1:1 584 000.

In 1937, the Sudbury Prospecting Syndicate and Erie Canadian Mines Limited carried out a prospecting, trenching and rock sampling program of the sulphide facies iron formation to the west of Samreid Lake. Low Ni values were locally encountered.

The same iron formation was outlined by Talvey Metal Mines Limited with a ground magnetometer survey in 1955. In 1957 the iron formation was tested with 29 diamond drill holes totalling 8281 feet (2525 m). Subeconomic assays of Fe and S were reported.

A number of individuals and companies carried out airborne magnetometer and electromagnetic surveys over portions of the map area from 1969 through to 1975. These include surveys by Moody and Pelchat, Hollinger Mines Limited, Sutherland, Robertson and Associates, Denis et al. and Consolidated Morrison.

In 1969, Chemalloy Minerals Limited carried out ground magnetometer and electromagnetic surveys and geological mapping in portions of Raimbault Township.

In 1976, Consolidated Morrison drilled two diamond drill holes totalling 2332 feet (710 m) to test two separate geophysical anomalies in Raimbault Township. No assays results were reported.

GENERAL GEOLOGY

The Ompa Lake greenstone belt of Archean supracrustal rocks forms an easterly trending, 30 km long belt that is approximately 5 km wide at the widest point. The greenstone belt extends from near the western end of Raimbault Township eastward to the western end of Poncet Township.

Proterozoic sedimentary rocks of the Huronian Supergroup form the northern boundary of the Archean supracrustal rocks in the west. Gabbroic and granitoid rocks of Proterozoic and Archean age occur to the south of the belt and to the north of the eastern portion of the belt. The Flack Lake and Little Quirke Lake Faults form repective north and south fault boundaries to the supracrustal rocks in a number of localities (Robertson 1977; Wood 1975).

The metamorphosed Archean supracrustal rocks in the map area (*see* Figure 2) consist mainly of arenaceous and argillaceous metasedimentary rocks and intermediate to felsic tuffs and lapilli tuffs. Narrow units of basalt flows are also found in the sequence and rare sulphide facies iron formation and calcite marble have been noted. Regional metamorphism ranging from greenschist to staurolite-almandine lower amphibolite facies has affected the Archean supracrustal rocks. The metamorphic grade increases from southwest to northeast across the map area.

Archean gabbro dikes and sills have also been mapped in the area cutting the supracrustal rocks.

Two varieties of Archean granitoids intrude the greenstone belt along the southern margin. These consist of tonalites and a granodiorite-quartz monzonite suite.

Nipissing gabbro and diabase of Proterozoic age occur as large intrusive bodies adjacent to the supracrustal belt in some localities and commonly as plugs and dikes cutting the supracrustal rocks. Proterozoic olivine diabase dikes of the Sudbury dike swarm were also rarely found in the map area.

Proterozoic sedimentary rocks of the Huronian Supergroup were found in fault contact to the north of the Archean rocks (*see* Figure 2).

Alteration of the Archean supracrustal rocks, generally in association with fault zones, includes silicification, carbonatization and chloritization.

Two large, easterly trending faults, the Flack Lake Fault and the Little Quirke Lake Fault, are the dominant structural features of the map area.

A strong penetrative foliation is apparent in the Archean metavolcanic and metasedimentary rocks and to a lesser degree in the Archean gabbros, increasing in intensity from southwest to northeast, coincident with the increase in metamorphic grade. Pillow facing directions and graded bedding indicate a consistent stratigraphic top direction to the north.

Exploration potential in the map area exists for structurally controlled gold deposits associated with altered fault zones; for volcanogenic massive sulphide deposits associated with the intermediate to felsic pyroclastic units and related exhalite horizons; and for stratabound gold mineralization related to sulphide facies iron formation.

ARCHEAN METAVOLCANIC ROCKS

The metavolcanic rocks of the map area consist mainly of intermediate to felsic tuff and lapilli tuff with subordinate horizons of basalt flows. Both of these main varieties of metavolcanic rocks are found interlayered with each other and with the Archean metasedimentary rocks.

The intermediate to felsic pyroclastic rocks extend through the map area with the thickest accumulations to the east of Ompa Lake. Individual units range from less than 50 m to greater than 200 m in width. These rocks are generally fine-grained (0.5-2 mm) but occasionally may be found with fragment sizes exceeding 10 mm. Quartz-feldspar porphyry horizons are relatively common, particularly in the southern part of the stratigraphy. Coarse-grained (>1 cm), poorly- to moderately-sorted, pyroclastic debris flows were also locally mapped. Massive to bedded chert horizons were occasionally found in association with the pyroclastic units, generally

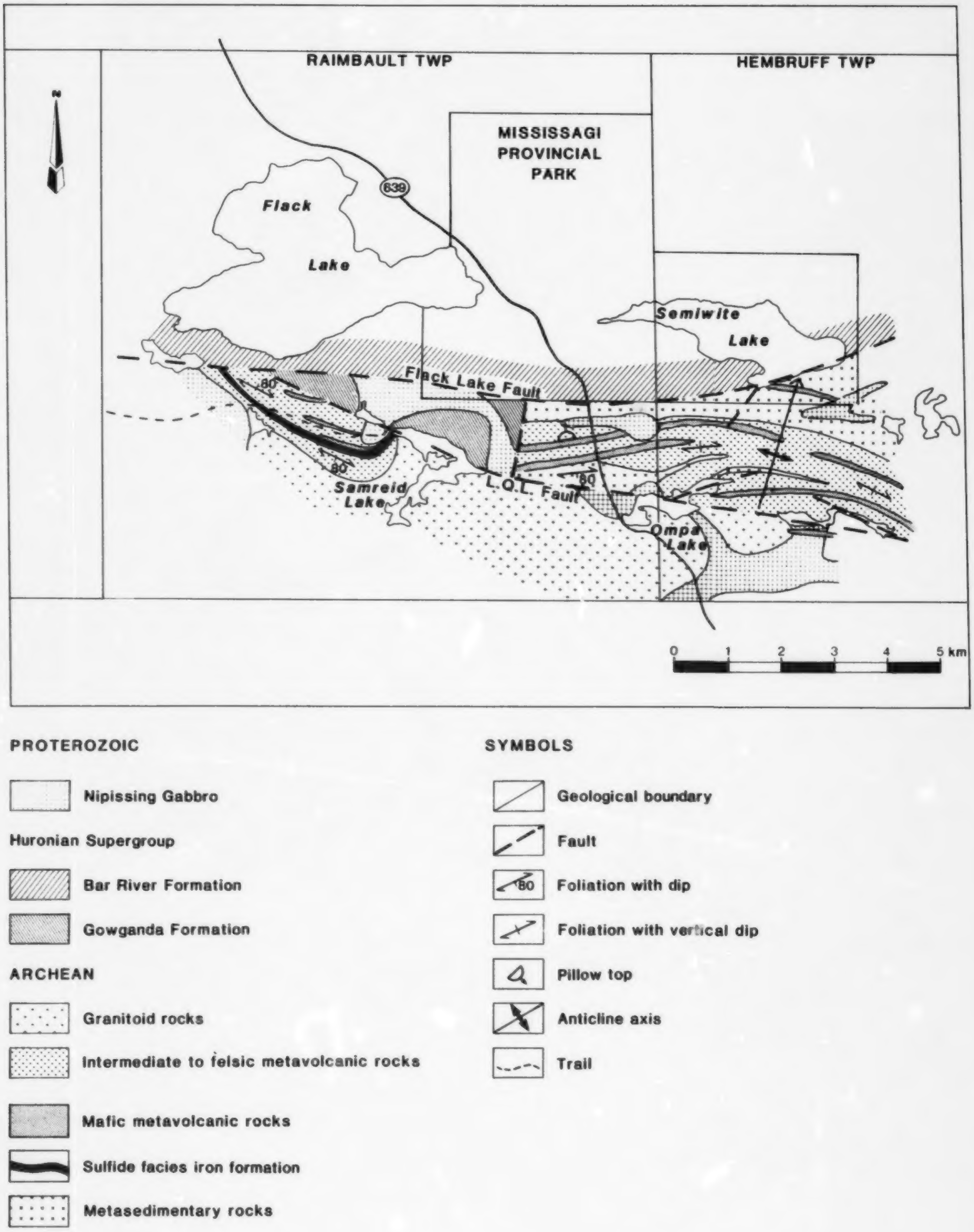
RAIMBAULT TWP
HEMBRUFF TWP
MISSISSAGI PROVINCIAL PARK
N
639
Flack Lake
Semiwite Lake
Flack Lake Fault
80
80
90
L.O.L. Fault
Samreid Lake
Ompa Lake
0 1 2 3 4 5 km
PROTEROZOIC
Nipissing Gabbro
Huronian Supergroup
Bar River Formation
Gowganda Formation
ARCHEAN
Granitoid rocks
Intermediate to felsic metavolcanic rocks
Mafic metavolcanic rocks
Sulfide facies iron formation
Metasedimentary rocks
SYMBOLS
Geological boundary
Fault
Foliation with dip
Foliation with vertical dip
Pillow top
Anticline axis
Trail

Figure 2. General geology of the 1991 map area, Ompa Lake greenstone belt.

at or near the tops of the units.

Relatively thin (<100 m) units of basalt flows are found locally in the sequence. These consist of massive and pillowed varieties with equigranular and plagioclase porphyritic textures. These units develope into chloritic schists towards the eastern portion of the map area as the degree of deformation and metamorphism increases. The appearance of almandine garnet in the basalts indicates the change from greenschist to lower amphibolite facies metamorphism.

A 3 km long unit of pyrrhotite-pyrite sulphide facies iron formation occurs in Raimbault Township and a 10 m wide unit of calcite marble outcrops along Highway 639. The marble may be of exhalitive origin or represent an area of pervasive carbonate alteration associated with a shear zone that trends through the unit. An exhalitive origin is favored by the author as the adjacent metasedimentary and metavolcanic rocks display only minor carbonate alteration.

ARCHEAN METASEDIMENTARY ROCKS

Metasedimentary rocks occur throughout the map area with the greatest concentrations lying to the south of Semiwite Lake. Both arenaceous and argillaceous varieties are common and are found intercalated with the metavolcanic rocks.

Arenaceous rock types occur as schistose rocks composed of variable quantities of quartz, feldspar, muscovite and biotite. Argillaceous varieties generally consist of biotite-quartz-feldspar schists with local muscovite. Almandine garnet, staurolite and andalusite were commonly developed as products of metamorphism in the northern and eastern portions of the map area. Narrow horizons of polymictic paraconglomerate locally occur along the southern margin of area in Raimbault Township. One of these horizons outcrops along Highway 639. These conglomerates are controversial as to whether they are of Archean or Proterozoic (Huronian) age. They were interpreted by Robertson (1977) to belong to the Gowganda Formation, occurring as slices caught up in the Little Quirke Lake Fault. The author has observed one conglomerate horizon in direct contact with an intermediate lapilli tuff unit to the west of Samreid Lake, approximately 600 meters south of the Little Quirk Lake Fault. This indicates that at least some of the conglomerates are of Archean age.

ARCHEAN GABBROIC ROCKS

Rare dikes and sills of Archean gabbro were mapped in the sequence. The gabbros are fine- to medium-grained, equigranular, display a penetrative foliation and have been subjected to the Archean regional metamorphism.

ARCHEAN GRANITOID ROCKS

Two main varieties of Archean granitoids intrude the greenstone belt along the southern boundary. These comprise older, massive to weakly gneissic, medium-grained, white tonalites and massive, medium-grained, pink granodiorites to quartz monzonites.

PROTEROZOIC MAFIC INTRUSIVE ROCKS

Large intrusive bodies of Nipissing gabbro and diabase are found locally along the southern boundary of the greenstone belt, along portions of the northern boundary in Raimbault Township and intruding the Archean supracrustal rocks as plugs and dikes. The gabbros are fine- to medium-grained, equigranular and massive and comprise mesocratic to leucocratic varieties. The Nipissing intrusions crosscut all of the major rock types including the Huronian sedimentary rocks.

A plagioclase porphyry variety of gabbro dike in the area may be related to the Matachewan type intrusions (G. Bennett, Resident Geologist, Sault Ste. Marie, personal communication, 1991).

Proterozoic olivine diabase dikes of the Sudbury dike swarm were occasionally found in the map area.

HURONIAN SEDIMENTARY ROCKS

Proterozoic sedimentary rocks of the Huronian Supergroup are in fault contact to the north of the greenstone belt. These comprise siltstones and quartzites of the Gowganda Formation to the north of Samreid Lake and quartzites of the Bar River Formation north of the Flack Lake Fault. Wood (1975) provides detailed descriptions of the Huronian sedimentary rocks in the area.

STRUCTURAL GEOLOGY

Two regional faults, the Flack Lake and the Little Quirke Lake faults, are the dominant structural features of the map area. The Little Quirke Lake Fault branches from the Flack Lake Fault near the western end of the greenstone belt (*see* Figure 2). The Flack Lake Fault trends east-northeast through the map area and forms the northern boundary of the greenstone belt. A reverse movement with a 72° south dip and a north side downdrop has been inferred by Wood (1975). The Little Quirke Lake Fault trends east-southeast along the southern portion of the map area. It is represented by a wide (>50 m) zone of strongly sheared rocks within a linear topographic depression. Mylonitic and cataclastic fabrics, and local silica and carbonate alteration are locally developed. A number of subsidiary faults and shears splay off of these major faults.

A strong penetrative foliation is apparent in all of the Archean metavolcanic and metasedimentary rocks and to a lesser extent in the Archean gabbros, increasing in intensity from southwest to northeast across the map area. The schistosity is bedding parallel, steeply dipping and changes from an average trend of 80° to 90° throughout most of the region to 110° to 130° to the south of Semiwite Lake, indicating a steep, northerly plunging antiform in that area. Wood (1975) has suggested a folding history for the area involving initial folding along a subhorizontal, east-trending axis which produced isoclinal folds and schistosity and later folding along almost vertical, north-plunging axes.

ECONOMIC GEOLOGY

The mineral potential of the Archean Ompa Lake greenstone belt was largely unknown due to the lack of exploration in the area. The western portion of the belt has a varied geological environment suitable for hosting precious and base metal mineralization types.

1. The potential exists for the occurrence of structurally controlled, gold mineralization associated with the fault zones in the region. Both the Flack Lake and Little Quirke Lake faults are large, regional structures which may have originated in the Archean. The Little Quirke Lake Fault occurs as a wide shear zone which is locally silicified and carbonatized. Subsidiary northeast- and northwest-trending splays off of this fault are similar in character. Minor (1 to 3%), disseminated pyrite is locally found with the shear zones.

2. The intermediate to felsic pyroclastic rocks and the associated chert horizons could host volcanogenic massive sulphide mineralization. Minor (1 to 2%), disseminated pyrite has been found occasionally with some of the units.

3. The pyrite-pyrrhotite sulphide facies iron formation located in Raimbault Township to the west of Samreid Lake has been traced intermittently along strike for over 3 km. It has apparently been assessed for base metal sulphides but may offer some potential for hosting stratabound gold mineralization.

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11. Lithogeochemical Study of the Archean Volcanic Rocks of the Whiskey Lake and Ompa Lake Greenstone Belts, Algoma District, Ontario

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INTRODUCTION

This report summarizes the activities and progress of the first two field seasons of a lithogeochemical study of the Whiskey Lake and Ompa Lake greenstone belts. The Whiskey Lake greenstone belt is bounded by latitudes 46°27'N to 46°31'N and longitudes 83°26'24"W to 82°46'54"W. The Ompa Lake greenstone belt is bound by latitudes 46°32'12" N to 46°35'30" N and longitudes 82°26'W to 82°47'W. The project is being carried out collaboratively by staff from the Department of Geology, Laurentian University and the Ontario Geological Survey (Jensen 1990; Rogers, this volume). The results and preliminary interpretations of the survey provide a data base to assist the mining industry in carrying out mineral exploration in this region. During this second field season, the eastern portion of the Whiskey Lake greenstone belt, and the western portion of the Ompa Lake greenstone belt were sampled. Preliminary results pertaining to the first field seasons activities are presented in Byron and Whitehead (1991).

The Whiskey Lake Belt is situated about 6 km southeast of the town of Elliot Lake, Ontario (*see* Figure 1), and is bounded by rocks of the Huronian Supergroup, preserved in the Quirk Syncline to the north, and Archean granitoid rocks to the south. Access to the western portion of the Whiskey Lake greenstone belt is by Highway 108 which connects the town of Elliot Lake with Highway 17 to the south. The Nordic Mine Road, about 4 km south of Elliot Lake on Highway 108, and the Ontario Hydro pole-line road, which continues east to Highway 553 north of Massey, can be used to access the northern portion of the study area. Portions of the Whiskey Lake greenstone belt area have been mapped, including Joubin Township, formerly Township 143 (Robertson 1961); Gaiashk Township, formerly Township 137 (Robertson 1962); Proctor and Deagle townships (Robertson 1977a). The Whiskey Lake area or Gerow Township, previously Township 130, was mapped originally by Douglas (1926) and most recently by McCrank et al. (1982).

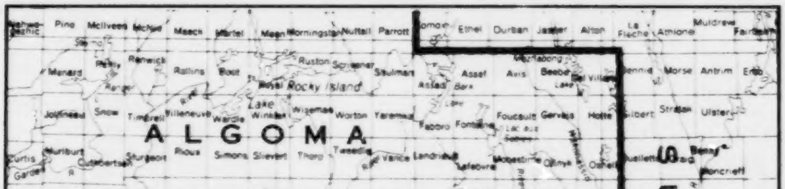


Figure 1. Location map for Whiskey Lake and Ompa Lake greenstone belts, scale 1:1 584 000.

Funds to support this project were provided by a grant from the Ministry of Northern Development and Mines to Laurentian University, as part of the Ontario Government's Elliot Lake Initiative.

The east-trending Ompa Lake greenstone belt is located about 15 km north of the town of Elliot Lake (Figure 1), in parts of Raimbault, Hembruff, Hughson, and Poncet townships. Access to the western portion of the Ompa Lake greenstone belt is by way of Highway 639 which is the continuation of Highway 108 north of the town of Elliot Lake. Segments of the Ompa Lake greenstone belt have been previously mapped by Robertson (1977b, Raimbault Township), and Wood (1975, Hembruff and Hughson townships). For a description of the geology of the two study areas, see Jensen (1990), Rogers (this volume), Robertson (1977a, 1977b), and Wood (1975). Preliminary gold, arsenic, carbon dioxide, copper, lead, and zinc contoured lithogeochemical-anomaly maps are presented in this report.

METHODOLOGY

Over the past two field seasons, 907 samples were collected from the Whiskey Lake greenstone belt incorporating parts of Proctor, Deagle, Gaiashk, Joubin and Gerow townships. During the past field season, 111 samples were collected from the western section of the Ompa Lake greenstone belt (Raimbault and Hembruff townships). Samples were collected along pace-and-compass traverses controlled by airphotos. Traverse lines were laid out to ensure a relatively consistent, unbiased, 400 m sample spacing. In order to ensure reliable background values were obtained, care was taken to collect representative samples of each major volcanic rock type encountered. Where alteration, mineralization or deformation was encountered, additional, more closely spaced samples were collected.

All samples were, and will continue to be, analyzed for silver, arsenic, gold, barium, bromine, calcium, cerium, cobalt, chromium, cesium, europium, iron, gallium, hafnium, iridium, lanthanum, lutetium, molybdenum, sodium, neodymium, nickel, rubidium, antimony, scandium, selenium, samarium, strontium, tantalum, terbium, thorium, uranium, tungsten, ytterbium and zinc by neutron activation. Copper, lead, zinc, strontium, rubidium, yttrium, and zirconium were analyzed by X-ray fluorescence. Major element analyses and carbon dioxide determinations were done on selected samples. The geochemical data, as well as the geological mapping data, will be entered into a digital data base format. The results of this lithogeochemical study will be presented on computer-generated anomaly maps to: 1) delineate areas which possess geochemical and geological features suggestive of economic mineralization; and 2) provide geochemical data to assist in the interpretation of the regional geology, under investigation by the Ontario Geological Survey (Jensen 1990; Rogers, this volume).

Using the abundances of pathfinder elements known to be elevated in proximity to massive base metal sulphide and gold mineralization (Beaudoin et al. 1987; Byron 1990; Davies et al. 1982; Govett 1983; Lesher et al. 1986; Parslow 1987; Thurston and Fryer 1983; Whyte and Nichol 1987; Whitehead and Davies 1988), the lithogeochemical data will be evaluated for anomalous metal concentrations. Evaluation of geochemical variations will be done in the context of the geology of the study area. The problems and limitations associated with reconnaissance multielement geochemical surveys of this nature have been addressed by Armour-Brown and Olesen (1984), Chork and Mazzucchelli (1989), Govett (1983) and Govett et al. (1975), and will be taken into consideration during the course of this study.

MINERAL EXPLORATION

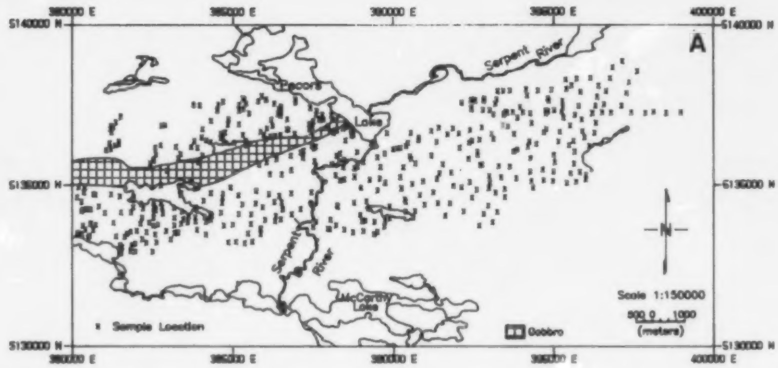
Previous exploration activity in the area around the Whiskey Lake greenstone belt has focussed on uranium in rocks of the Huronian Supergroup. The Whiskey Lake greenstone belt has not been explored extensively for precious and base metal mineralization. Few signs of recent or past exploration activity were encountered during the sampling program.

In the early 1950s, Teck Exploration Company Limited carried out an exploration program in search of nickel and copper. In December 1956, El Pen-Rey Oil and Mines Limited drilled 9 diamond-drill holes on a group of 27 claims within Gerow Township, looking for copper and nickel mineralization. In 1967, Kerr-McGee Corporation drilled 2 diamond-drill holes near the present site of the Elliot Lake airport in Proctor Township, and 1 diamond-drill hole in Joubin Township, looking for gold mineralization. In May 1988, BP Canada Inc. conducted a helicopter-borne magnetometer and very low frequency electromagnetic (VLF-EM) surveys on a 9 claim group within Joubin Township.

Assessment records for the Ompa Lake greenstone belt indicate that exploration for gold or base metals has not been vigorously pursued. In 1937, a sampling program in search of nickel mineralization was undertaken in Raimbault Township by Erie Canadian Mines Ltd. In 1957, Talvey Metals Mines Ltd. drilled approximately 8281 feet (2760 m) in Raimbault Township and assayed for iron and sulphur. In 1969, ground magnetometer, electromagnetic and geology surveys were conducted by Chemalloy Minerals Ltd. within Raimbault Township. In 1970, United Nuclear Mines carried out an airborne magnetometer and electromagnetic survey in Raimbault and Hembruff townships. A ground magnetometer and geological survey was conducted by Trinity Chibougamau, in 1965, on their Iron Lake property covering parts of Hughson and Poncet townships. This was followed up by 2 diamond-drill holes, totalling 1541 feet (470 m), with assays for iron and sulphur.

LITHOGEOCHEMICAL ANOMALY MAPS

Sample distribution is illustrated in Figure 2a. The data presented on these maps includes only samples that were col-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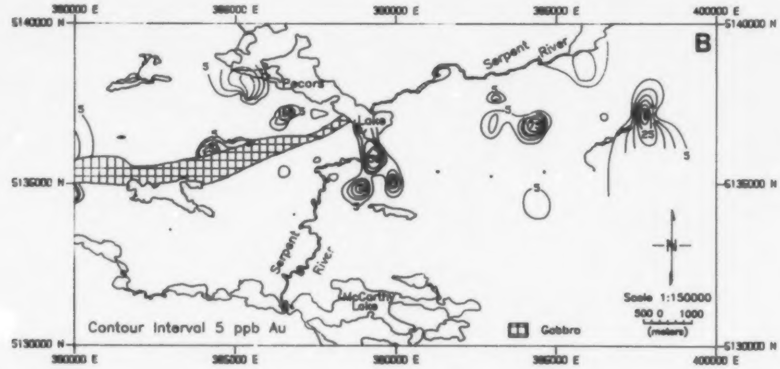
A
Serpent River
Pecors
Lake
Serpent River
McCarthy Lake
Sample Location
Gabbro
Scale 1:150000
500 0 1000
(meters)

Figure 2a. Lithogeochemical sample locations. 1990 field season samples.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McCarthy Lake
5
25
Contour Interval 5 ppb Au
Gabbro
Scale 1:150000
500 0 1000
(meters)

Figure 2b. Gold anomaly map. Contour interval 5 ppm Au.

lected from the Whiskey Lake greenstone belt during the 1990 field season.

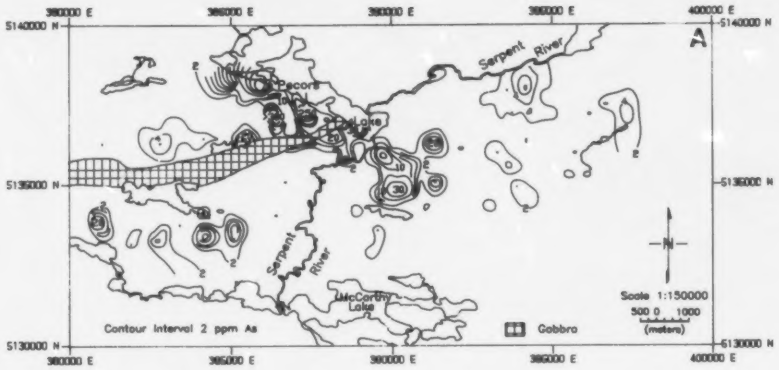
All anomaly maps (Figures 2b to 5) are computer generated. Average threshold values, or Clarke values (Davies et al. 1982; Levinson 1980; Whitehead et al. 1980; Whitehead et al. 1979), for rocks of the study area, have been contoured and presented on 1:150 000 scale lithogeochemical anomaly maps. Normalized copper, lead, and zinc contoured anomaly maps are presented to illustrate a method of dealing with different background elemental abundances and thresholds that occur in different rock types. Arsenic, gold and carbon dioxide data are not normalized because background abundances in different rock types approach the detection limit of the analytical method. All threshold values are to be considered as provisional.

Arsenic, Carbon Dioxide, and Gold

Arsenic (As) and carbon dioxide (CO_2) are used by exploration geologists as indicators of gold mineralization (Beaudoin et al. 1987; Byron 1990; Davies et al. 1982; Kerrich and Fyfe 1981; Phillips and Brown 1987; Whitehead and Davies 1988). Preliminary contoured lithogeochemical anomaly maps of these elements and compounds have been constructed for the study area.

The average value of gold for all major rock types is 4.0 ppb. The detection limit for gold by neutron activation analysis is 5.0 ppb, therefore, everything greater than the detection limit will be considered anomalous (Figure 2b). Areas of anomalous gold values are located west of Pecors Lake in close proximity to the iron formation, and east to southeast of Pecors Lake, spatially coincident with discordant shear zones (Figure 2b).

The average value of arsenic in igneous rocks is 2.0 ppm; arsenic is contoured using this value as the threshold value and contour interval (Figure 3a). Anomalous regions along the southwest shores of Pecors Lake, and directly north of Depot Lake, coincide with numerous outcrops of sulphide-facies iron formation. Weaker anomalies define a linear trend just east of Depot Lake and correspond to the contact region between the greenstone belt and granitoid rocks to the south. A series of anomalies south of the Serpent River between Whiskey Lake and Pecors Lake correlate with 055°-trending shear zones recognized in the field.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Contour Interval 2 ppm As
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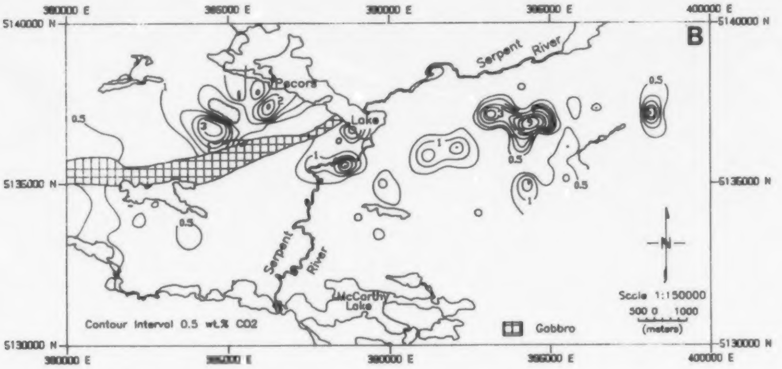
Figure 3a. Arsenic anomaly map. Contour interval 2 ppm As.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B
Serpent River
Pecors Lake
McCarthy Lake
0.5
Contour Interval 0.5 wt.% CO2
Gabbro
Scale 1:150000
500 0 1000
(meters)
N

Figure 3b. Carbon dioxide anomaly map. Contour interval 0.5 weight % CO_2.

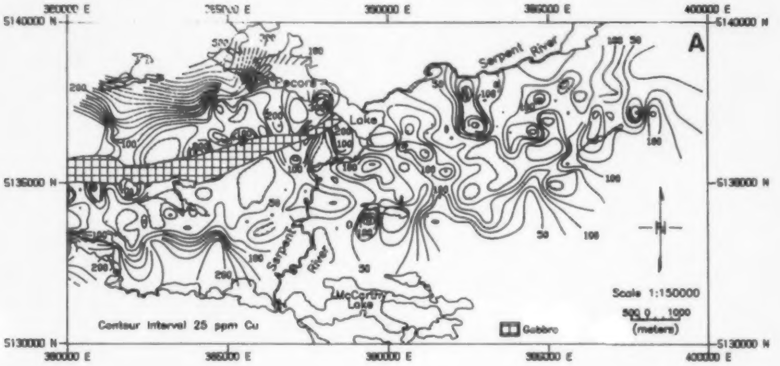
Whitehead et al. (1980) determined the CO_2 background value for relatively unaltered rocks around the Timmins mining district to be less than 1.0%. In Figure 3B, a contour interval of 0.5 weight % CO_2 is used. Carbon dioxide values above background define anomalous zones that trend 055° east of Pecors Lake. A second anomalous area occurs west of Pecors Lake in close proximity to the iron formation; however, these second CO_2 anomalies are associated with relatively thin units of altered and sheared magnesium tholeiites.

Copper, Lead, and Zinc Unnormalized and Normalized Anomaly Maps

Copper, lead, and zinc enrichments around massive sulphide deposits have been documented by various workers (Govett 1983; Parslow 1987; Whyte and Nichol 1987). Two different types of anomaly maps are presented. One anomaly map (Figure 4a) was generated using a threshold and contour interval equal to the average value of copper, determined for the entire data set regardless of rock type (Levinson 1980). Because different rock types can have different threshold values, it is desirable to use normalized abundances of copper, lead and zinc (Figure 4b). For example, if rock "A" has a threshold value of 10 ppm Cu, and rock "B" has a threshold value of 250 ppm Cu, then choosing a common threshold value is impossible. Normalizing the data involves evaluating each sample in relation to the threshold value determined for the lithological group the sample belongs to, i.e., (sample - threshold)/threshold = normalized value to be contoured. The resulting value represents the relationship between the sample value and the threshold for a given element. Therefore, a value of 0 indicates that the sample value and threshold value are the same. Any value greater than 0 is above background and can be considered anomalous.

Samples were sorted into mafic, intermediate, and felsic lithologies based on silica abundance. Frequency distribution diagrams were constructed for each element of the three major rock groups in the study area. Threshold values used in the normalization calculations were determined empirically from the histograms.

An average value of 25 ppm Cu for all rock types of the study area is used as the contour interval on the unnormalized copper anomaly map (Figure 4a). It appears that copper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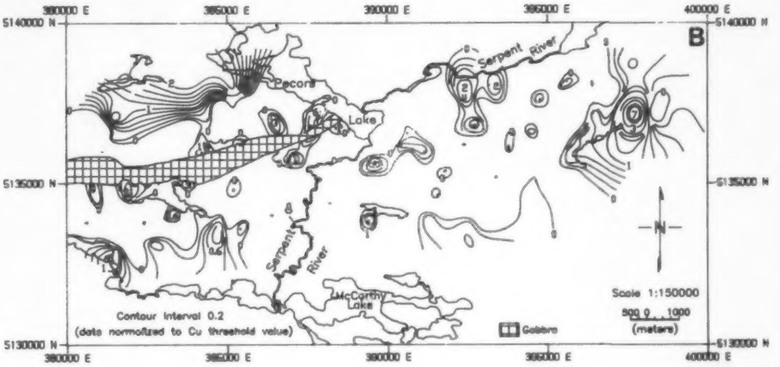
5140000 N
5135000 N
5130000 N
Serpent River
Pecors
Lake
McCarthy Lake
N
Scale 1:150000
500 0 1000
(meters)
Gabbro
Contour interval 25 ppm Cu
200
100
50

Figure 4a. Copper anomaly map. Contour interval 25 ppm Cu.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5130000 N
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Pecors
Lake
McCarthy Lake
N
Scale 1:150000
500 0 1000
(meters)
Gabbro
Contour interval 0.2
(data normalized to Cu threshold value)
2
1
0

Figure 4b. Normalized copper anomaly map. Contour interval 0.2.

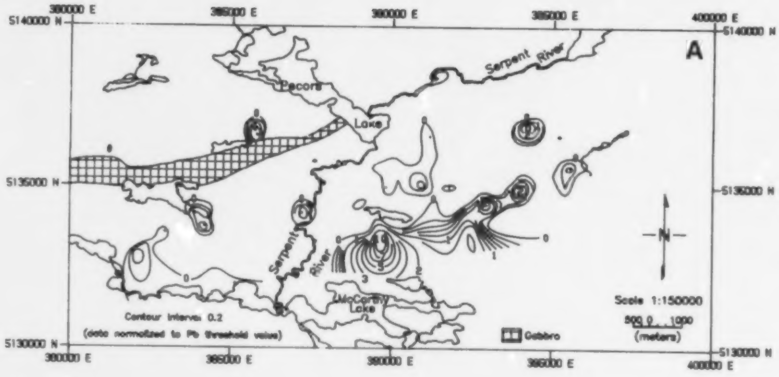
may be preferentially concentrated in northeasterly oriented anomaly patterns east of Pecors Lake. However, it is not until the data are normalized (Figure 4b) that the distinct northeast trend stands out. Normalizing copper (Figure 4b) has effectively minimized the noise that exists on the unnormalized copper map (Figure 4a). The normalized lead map (Figure 5a) clearly depicts the presence of anomalous lead mineralization along two northeast-trending structures. On the normalized zinc map (Figure 5b), the northeast-trending structures are not as distinct as in the normalized copper (Figure 4b) and lead (Figure 5a) anomaly maps.

Correspondence between Geochemistry and Geology

The lithogeochemical anomaly maps presented in this report depict two distinct trends: 1) a 290° anomaly trend that is parallel to the strike of stratigraphy, and 2) a 055° anomaly trend that is related to late, discordant structures, that are probably shear zones. The Serpent River between Pecors and Whiskey lakes, as well as the gabbro which cuts the study area west of Pecors Lake, also fall along the 055° trend. Anomalous concentrations of gold pathfinder elements such as arsenic and carbon dioxide, and gold indicate that the iron formations in the vicinity of Pecors Lake, and the 055°-trending shear zones east to southeast of Pecors Lake hold the greatest potential for gold mineralization. Copper and lead anomaly patterns indicate that the northeast-trending structures also represent exploration targets.

FUTURE WORK

By the end of the 1992 field season, sampling will be completed for the Ompa Lake greenstone belt. For both the Whiskey Lake and Ompa Lake greenstones belts, lithogeochemical evaluations will be carried out in the context of the bedrock geology of the area, mapped by Jensen (1990) and Rogers (this volume). This will entail the continued search for correlations between areas of anomalous geochemistry and specific geological features. The lithogeochemistry will be presented in the form of anomaly maps. Areas that display anomalous geochemistry, or which are characterized by geology known elsewhere to be favourably disposed to the presence of massive base metal sulphide or gold mineralization, will be investigated in greater detail.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0
1
2
3
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Scale 1:150000
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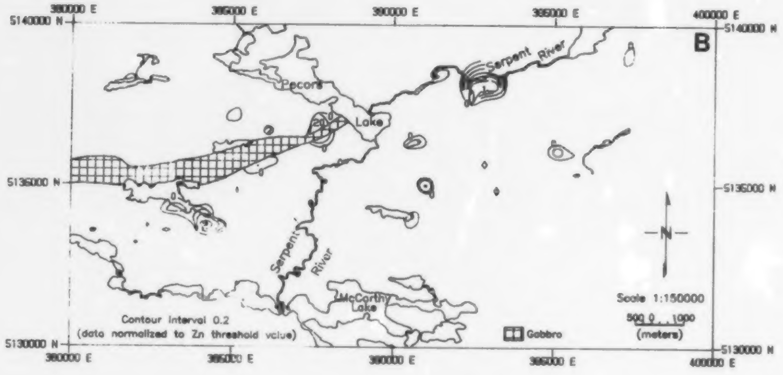
(meters)
Contour interval 0.2
(data normalized to Pb threshold value)
Gabbro

Figure 5a. Normalized lead anomaly map. Contour interval 0.2.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Lake
Serpent River
McCarthy Lake
N
Scale 1:150000
500 0 1000
(meters)
Contour interval 0.2
(data normalized to Zn threshold value)
Gabbro

Figure 5b. Normalized zinc anomaly map. Contour interval 0.2.

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12. Magmatic Platinum Group Elements and Copper + Nickel Sulphide Mineralization along the base of the East Bull Lake Gabbro-Anorthosite Intrusion

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INTRODUCTION

This report documents the general character of a recently discovered zone of platinum group element (PGE) and associated copper + nickel (Cu + Ni) mineralization from the basal portion of the East Bull Lake gabbro-anorthosite intrusion. This zone represents the most promising exploration target identified to date from the current investigation into the mineral potential of Early Proterozoic mafic and ultramafic intrusive rocks occurring in Gerow, Boon, Shibananing, Lockeyer and Mandamin townships (*see* Figure 1). Detailed descriptions of the results from reconnaissance lithogeochemical sampling of these intrusive rocks (Peck and James 1990, 1991) and of detailed geological mapping (at a scale of 1:1000 and 1:5000) of the East Bull Lake intrusion (Peck and James 1991) will be presented in a forthcoming open file report. The geology and platinum group element geochemistry of the eastern part of the East Bull Lake intrusion is the subject of an M.Sc. thesis initiated during the 1991 field season (P.T. Chubb).

GEOLOGICAL SETTING

The study area (Figure 1) hosts several mafic intrusions (Figure 2) which were emplaced into Archean intermediate to felsic plutonic rocks (Algoman granitic suite and Parisien Lake syenite) and mafic to felsic metavolcanic rocks (Whiskey Lake greenstone belt, Jensen 1990). The largest of these is the 2480 Ma (Krogh et al. 1984) East Bull Lake intrusion, which is a differentiated lopolith outcropping over an area of 43 km^2. The intrusion is 20 km long, up to 4 km wide, and has a minimum thickness of 800 m (Ejeckam et al. 1990). Recent mapping by the present authors and BP Minerals Ltd. has shown that the East Bull Lake intrusion is nearly continuous into the western lobe of the Shakespeare-Dunlop intrusion (Figure 2), providing support for the suggestion that these two intrusions are coeval (e.g., Krogh et al. 1984; James and Born 1985).

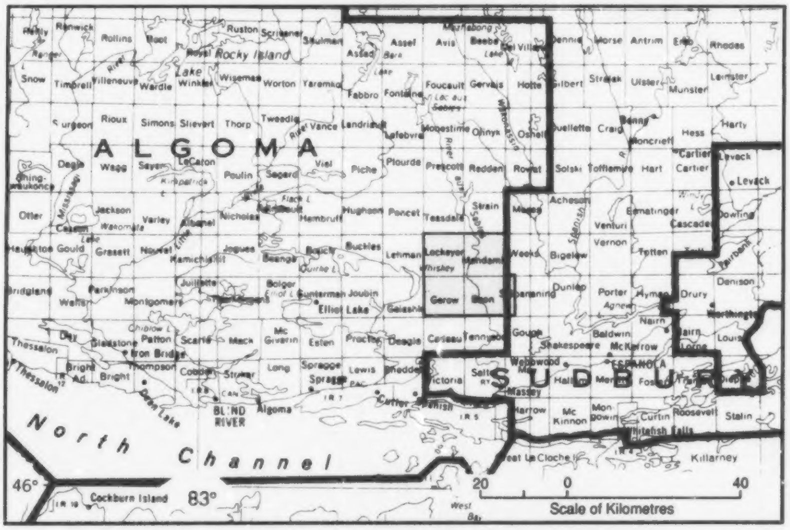


Figure 1. Location map of the Elliot Lake area, scale 1:1 584 000.

Funds to support this project were provided by a grant from the Ministry of Northern Development and Mines to Laurentian University, as part of the Ontario Government's Elliot Lake Initiative.

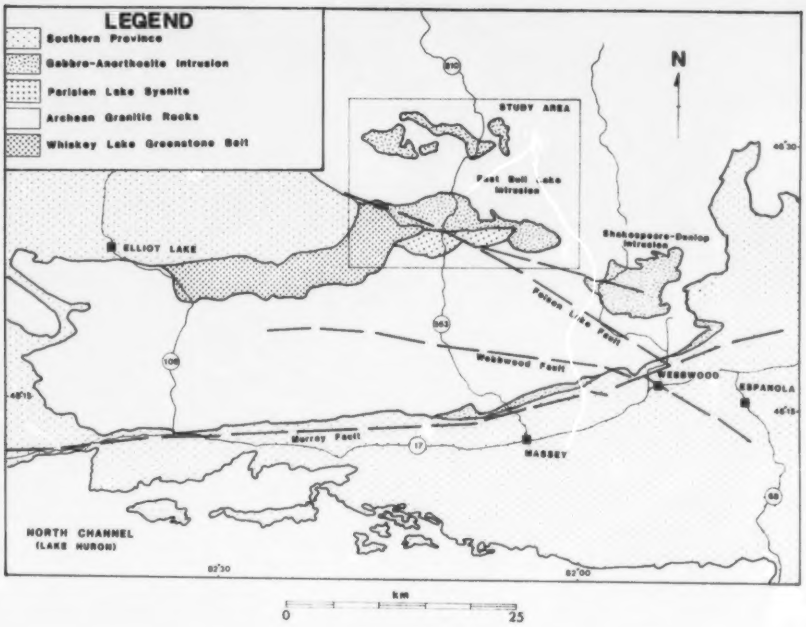


Figure 2. Location of mafic intrusions in the Elliot Lake–Espanola region.

There is increasing petrological and geochemical evidence favouring a model in which these intrusions are part of a major episode of mafic magmatism comprising the basal Huronian tholeiitic basalts, the Matachewan dike swarm (Ontario Geological Survey 1991) and possibly additional anorthositic plutons occurring along the Murray fault (Figure 2), the Sudbury basin and the northern part of the Grenville Province (*see* Ontario Geological Survey Compilation Map 2361, Sudbury-Cobalt). This magmatic event is attributed to the opening of a major continental rift along the southern part of the Superior Province during the Early Proterozoic (Innes 1978; Jolly 1987; Prevec and Baadsgaard 1991a, 1991b).

Smaller mafic intrusions occurring to the north of the East Bull Lake intrusion (Figure 2) are believed to represent part of the 2219 Ma (Corfu and Andrews 1986) Nipissing diabase suite (Jambor 1971). However, this proposed association is based on petrological and field observations alone, and remains to be tested using geochemical and/or isotopic information.

Our current understanding of the geology and petrology of the East Bull Lake intrusion is discussed in Peck and James (1991). This understanding is based on previous detailed investigations (Born 1979; McCrank et al. 1989) and preliminary results from the current study. Generalized geological interpretations for both the western and eastern parts of the East Bull Lake intrusion are given in Figures 3 and 4, respectively.

MINERAL EXPLORATION

Gallo Exploration Services Inc. (Toronto) remains the major claim-holder in the area, with approximately 150 claims within a contiguous block covering nearly the entire eastern portion of the intrusion within Boon and Shibananing townships (Figures 1, 3 and 4). Gallo Exploration continued their program of trenching and assaying (PGE, Cu, Ni), concentrating on poddy massive and semi-massive Fe + Cu + Ni sulphide occurrences hosted by the Parisien Lake deformation zone (e.g., Site 1, Figure 3). Descriptions and analytical data for these occurrences are given by Peck and James (1990, 1991). Grab samples from these occurrences have returned up to several percent copper and nickel, and low ppm-levels of combined Pd + Pt + Au (E. Gallo, Gallo Exploration Services Inc., personal communication, 1990). Selected assay data for these occurrences are given in Table 1 (hydrothermal sulphide mineralization).

During August of the current year, Inco Exploration and Technical Services Ltd. staked a series of claims to the west of, and adjoining, the claim block held by Gallo Exploration, and encompassing all available ground in the western part of the intrusion (predominantly in Gerow Township, Figure 1). Inco commenced initial surface exploration of these claims during September. The only part of the intrusion that has not been staked lies within a 13 km^2 block in the central part of the intrusion (Figure 3), representing the remnant of an originally much larger area which was withdrawn from staking for the purpose of a nuclear fuel waste management study conducted by the Atomic Energy of Canada Ltd. (AECL) during the 1980s.

CHARACTERISTICS OF PGE AND BASE METAL MINERALIZATION IN THE LEUCOGABBRONORITE ZONE

As a result of an ongoing lithogeochemical survey of the mafic

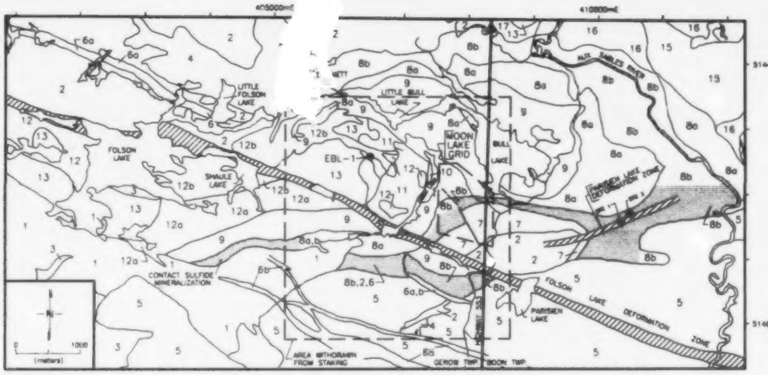


Figure 3. Generalized geology of the western part of the East Bull Lake gabbro-anorthosite intrusion. Compiled by D.C. Peck. Modified *from* McCrank et al. (1982); *see* Peck and James (1991) for discussion. Topographic reference map NTS 41 J/8.

Legend:
17—Proterozoic granite,
16—Nipissing gabbro and diabase,
15—Huronian sedimentary rocks,
14—Diabase
East Bull Lake Intrusion (6–13):
13—Metamorphosed gabbro,
12—Vari-Textured Quartz Gabbro Zone (a) massive gabbro and anorthositic gabbro (b) layered gabbro and anorthositic gabbro,
11—Layered Gabbro Zone,
10—Olivine Gabbronorite Zone,
9—Rhythmically-Layered Gabbronorite Zone,
8—Leucogabbronorite Zone (a) leucogabbronorite subzone (b) anorthosite subzone (c) nodular-textured anorthosite,
7—Border Zone,
6—Feedre dikes (a) massive gabbro (b) plagioclase porphyry diabase
Archean:
5—Parisien Lake syenite,
4—Intermediate metaplutonic rocks,
3—Metagabbro,
2—Algoman intermediate to felsic metaplutonic rocks,
1—Whiskey Lake greenstone belt.

intrusive rocks in the study area, and detailed geological mapping of the previously unmapped eastern part of the East Bull lake intrusion (Figure 4), extensive occurrences of disseminated pyrrhotite + chalcopyrite + pentlandite mineralization have been identified from the Leucogabbronorite Zone (Peck and James 1991). This section will briefly describe the geology in the vicinity of the mineralization, the general petrographic characteristics of the sulphide mineralization, and preliminary assay data from the current study.

Geological Features

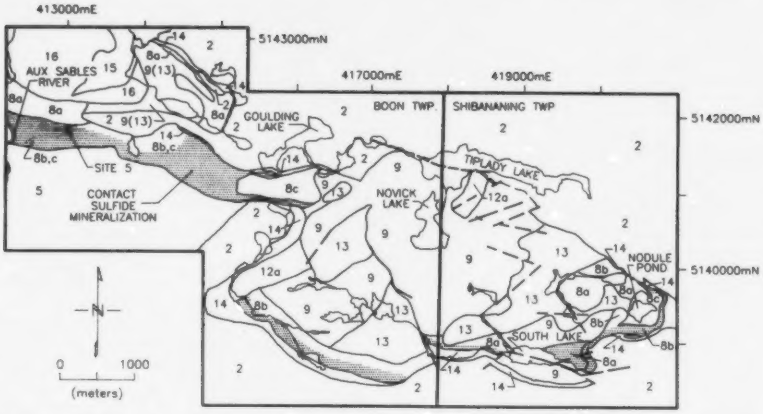
The distribution of primary sulphide mineralization within the Leucogabbronorite Zone is shown in Figures 3 and 4. The mineralization is herein referred to as **contact sulphide mineralization** to distinguish it from other primary and hydrothermal (formerly type 1 sulphides, Peck and James 1990) sulphide occurrences in the intrusion, and to highlight its consistent spatial association with the contact between the intrusion and older Archean rocks (Figures 3 and 4). Contact sulphide mineralization incorporates both type 2 and type 3 sulphide mineralization (Peck and James 1990, 1991). The contact sulphide mineralization is best exposed along the southern margin of the intrusion, where it forms a generally continuous zone extending approximately 16 km from Folson Lake in the west, to Nodule Pond in the east (Figures 3 and 4). The presence, abundance and distribution of comparable sulphide mineralization along the northern margin of the intrusion is less well constrained because of extensive faulting (e.g., Tiplady Lake area, Figure 4) and the relatively small amount of outcrop along this contact. However, disseminated chalcopyrite is locally present in blue quartz-bearing anorthositic rocks along the northern contact of the intrusion north of Bull Lake (subunit 8b, Figure 3).

Contact sulphide mineralization is most abundant immediately east of Moon Lake (Figure 3). The Moon Lake area hosts several trenches excavated prior to 1943 (Moore and Armstrong 1943) and was explored for Ni-Cu mineralization by El Pen-Rey Oil and Mines Ltd. during the 1950s. Detailed mapping (at a scale of 1:1 000) and lithogeochemical sampling in this area was conducted on a flagged grid (Figure 3) during the 1991 field season, and provides the first detailed account of the contact sulphide mineralization. The results of this research will be presented in a forthcoming open file report. The extent of the contact sulphide mineralization in other areas is less well defined, owing to a combination of lesser amounts of outcrop and less detailed mapping. The mineralization occurs in a variety of rock types, but is always proximal to the base of the Leucogabbronorite Zone (Anorthosite Subzone).

Figure 5 presents three idealized stratigraphic sections through the Anorthosite Subzone of the Leucogabbronorite Zone from different localities. These sections illustrate the large degree of textural and lithological variation in the vicinity of the contact mineralization.

In the Moon Lake area (Figure 5a), the mineralization is hosted by a texturally heterogeneous section of the Anorthosite Subzone (unit 8b, Figure 3), and locally extends into the Border Zone (unit 7, Figure 3). The area is cut by a number of small branching faults and major fractures, which have caused local shearing and extensive recrystallization of the rocks.

The Border Zone comprises stringer veins, dikes and irregularly shaped bodies of fine- to coarse-grained gabbronorite, quartz-bearing gabbronorite and leucogabbronorite that have intruded tonalitic to dioritic Algoman intrusive rocks. The latter occur as isolated fragments of extremely variable size (a few centimetres to several tens of metres in length) and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BOON TWP.
SHIBANANING TWP
TIPLADY LAKE
NOVICK LAKE
NODULE POND
SOUTH LAKE
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Figure 4. Generalized geology of the eastern part of the East Bull Lake gabbo-anorthosite intrusion. Geology (1991) by D.C. Peck and P.T. Chubb. Topographic reference map NTS 41 J/8. *See* Figure 3 for legend.

Table 1. Selected Pd, Pt, Au, Ni and Cu analyses for the East Bull Gabbro-Anorthosite intrusion.

Sample	Location	Host	Type	Pd	Pt	Au	Ni	Cu	Pd:Pt	Cu:Ni	Pd + Pt + Au
90DCP-353	A	3	HYDR	1520	275	280	3760	33600	5.53	8.94	2075
90DCP-354	A	3	HYDR	1550	230	180	9770	24360	6.74	2.49	1960
90DCP-372	B	1	CONT	1440	355	70	1340	3480	4.06	2.6	1865
90DCP-373	D	1	CONT	1400	340	88	338	6000	4.12	17.8	1828
90DCP-407	B	1	CONT	1750	343	115	960	2790	5.1	2.91	2208
90DCP-488	A	3	HYDR	2180	475	550	1730	56300	4.59	32.5	3205
90DCP-490	A	3	HYDR	1790	545	33	10300	2710	3.28	0.26	2368
90DCP-497	A	3	HYDR	2300	171	70	4750	15	13.5	<0.01	2541
90DCP-499	A	4	HYDR	1370	1060	100	367	8200	1.29	22.3	2530
90DCP-500	A	3	HYDR	1600	189	140	2867	39340	8.47	13.7	1929
91DCP-432	B	1	CONT	1300	630	130	1010	3370	2.06	3.34	2060
91DCP-467	B	1	CONT	2000	940	120	2630	7080	2.13	2.69	3060
91DCP-473	B	1	CONT	990	940	52	668	2790	1.025	4.18	1982
91DCP-488	B	1	CONT	530	530	93	196	808	1	4.12	1153
91DCP-490	B	2	CONT	700	570	200	328	4320	1.22	13.2	1470
91DCP-496	B	2	CONT	620	1300	90	203	1390	0.48	6.85	2010
91DCP-508	B	1	CONT	3200	900	120	138	709	3.56	5.14	4220
91DCP-510	A	1	CONT	4100	1700	240	545	3360	2.41	6.17	6040
91DCP-512	A	1	CONT	1900	510	83	943	3150	3.73	3.34	2493
91DCP-600	C	1	CONT	1300	250	66	1160	2190	5.2	1.89	1616
91DCP-603	C	1	CONT	2600	590	150	1390	5410	4.41	3.89	3340

***Notes:** Analyses refer to surface samples collected by the authors. Analyses were carried out by the Geoscience Laboratories of the Ontario Geological Survey (1990 samples) and by X-ray Assay Laboratories (1991 sampels). Pd, Pt and Au are reported in ppb. Ni and Cu are reported in ppm. nd - not determined*
***Key:** Location: A—Gallo Exploration Claims within and adjacent to the Parisien Lake deformation zone; B—Moon Lake area; C—Goulding Lake area; D—Nodule Pond area. Host Rock: 1—anorthosite or leuco-gabbronorite; 2—pyroxenite (inclusion in Anorthosite Subzone); 3—massive sulphide from shear zone; 4—massive magnetite from shear zone; Sulphide Type: CONT—contact sulphide mineralization; HYDR—hydrothermal sulphide mineralization.*

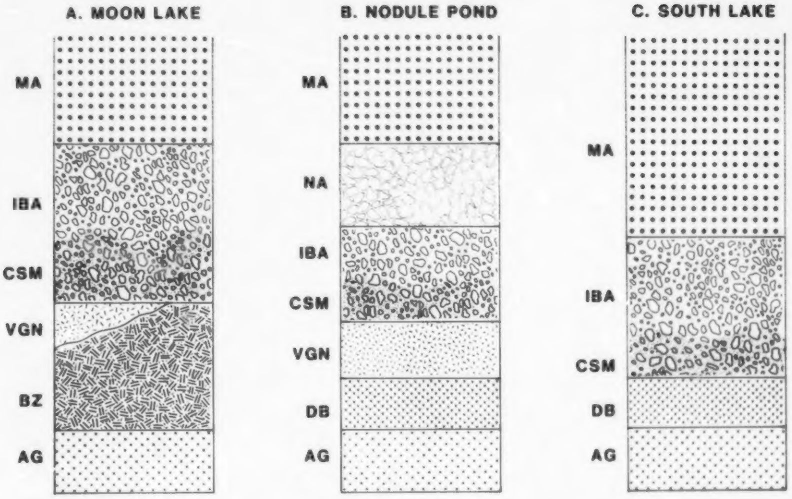

Figure 5. Idealized stratigraphic variations for the Anorthosite Subzone of the Leucogabbronorite Zone, East Bull Lake gabbro-anorthosite intrusion. Abbreviations: AG—Algoman granitic rocks; BZ—Border Zone; VGN—vari-textured gabbronorite grading to pyroxenite; CSM—contact sulphide mineralization (stripled); IBA—inclusion-bearing anorthosite and leucogabbronorite; MA—massive anorthosite and leucogabbronorite; NA—nodular-textured anorthosite; DB—diabase. See text for description of units.

shape, and are generally impoverished in quartz relative to undisrupted Algoman intrusive rocks seen elsewhere. The relative proportions of gabbroic rock to granitic fragments is also extremely variable. Locally, a fringe of quartz-rich gabbro surrounds quartz-free leucocratic diorite inclusions, suggesting that some of the Algoman intrusive fragments occurring within the Border Zone experienced partial melting during emplacement of the gabbro.

The Border Zone also contains aphyric, massive, fine-grained diabase dikes up to 10 m wide. These dikes are correlated with post-East Bull Lake intrusion diabase dikes (unit 14, Figures 3 and 4) that are believed to predate the emplacement of the Nipissing gabbroic rocks (McCrank et al. 1989), but have yet to be assigned a precise age. Older, porphyritic diabase dikes are rarely observed within the border zone. They are commonly glomeroporphyritic, and contain irregularly shaped aggregates of coarse plagioclase up to several centimetres in diameter. The porphyry dikes are tentatively correlated with plagioclase-phyric diabase dikes occurring along the southern margin of the intrusion (unit 6b, Figure 3), which are believed to represent feeders to the anorthositic parts of the intrusion.

The Border Zone appears to have originated through the brecciation and partial assimilation of Algoman basement by gabbroic magmas parental to the overlying East Bull Lake intrusion. The occurrence of two petrographically distinctive gabbroic phases, only one of which contains quartz, may reflect the existence of at least two parental magmas for the intrusion.

The Anorthosite Subzone, in the vicinity of Moon Lake, comprises a discontinuous basal zone of quartz-bearing, vari-textured gabbronorite, melanogabbronorite and pyroxenite that is overlain by a thick sequence of inclusion-bearing anorthositic rocks displaying heterogeneous textures. The latter commonly display indistinct nodular textures, involving irregularly distributed, rounded to lens-shaped plagioclase aggregates up to 30 cm in diameter, set in a vari-textured gabbroic to pyroxenitic matrix. Where massive, the anorthositic rocks are typically coarse- to very coarse-grained (plagioclase up to 5 cm long), and contain up to 20% clotty postcumulus pyroxene. The inclusion-bearing anorthosite and leucogabbronorite also host discontinuous gabbroic layers, up to 5 m thick and several metres long. These layers are believed to have crystallized from pockets of mafic postcumulus liquids residual from the formation of the anorthosite. The gabbroic layers typically have undulose contacts with the enclosing anorthositic rocks (Photo 1), and locally display harrisitic structures, with the long axes of the pyroxenes oriented perpendicular to the layer contacts. Dendritic gabbronorite is also observed (Photo 2), comprising fan-shaped aggregates of pyroxene up to 20 cm long.

Blue to purple quartz is commonly present in the gabbroic rocks of the anorthosite subzone. It is unclear whether the quartz is primary or metamorphic in origin. The ubiquitous replacement of primary pyroxene by amphibole during metamorphism of the East Bull Lake intrusion would have provided free silica which may have crystallized as quartz. However, the abundance of quartz in the Anorthosite Subzone is generally much greater than seen elsewhere in the intrusion, suggesting that at least some of the quartz is primary. The inclusion-bearing anorthosite also hosts rounded to elongated xenoliths of quartz-bearing melanogabbronorite and pyroxenite. The latter comprise cumulus pyroxene and lesser cumulus plagioclase, and a trace to 1% disseminated blue quartz. The inclusions may represent clasts of pre-existing ultramafic layers,

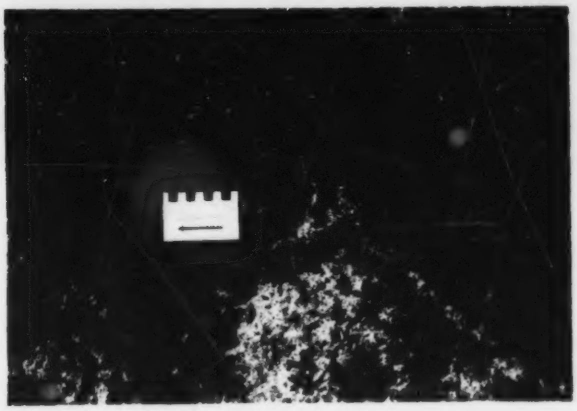

Photo 1. Irregular, but sharply-defined contact between a discontinuous vari-textured gabbronorite layer (top of photo) and an enclosing inclusion-bearing anorthosite unit, Anorthosite Subzone, Moon Lake area, East Bull Lake intrusion.

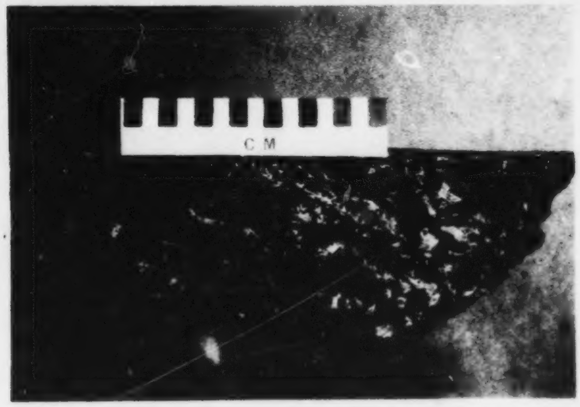

Photo 2. Dendritic gabbronorite, East Bull Lake intrusion.

such as the pyroxenite unit locally developed at the base of the Anorthosite Subzone at Moon Lake. Alternatively, they may have crystallized from pockets of primitive magma, which was immiscible with the more alumina- and alkali-rich parental liquids for the anorthosites. Evidence for liquid immiscibility during the emplacement of the East Bull Lake intrusion is found within the Border Zone, in which emulsion-like textures, involving quartz-bearing and quartz-free gabbroic rocks are commonly developed. In the vicinity of Nodule Pond (Figure 4), contact sulphide mineralization is hosted by vari-textured and inclusion-bearing leucogabbronorite which underlies a thick sequence of nodular-textured leucogabbronorite and anorthosite. The detailed stratigraphy for this locality (Figure 5b) involves four distinctive units, including (with increasing stratigraphic elevation):

1. one or two generations of mafic dikes, including aphyric, fine-grained diabase, and fine- to medium-grained, locally glomeroporphyritic diabase breccia,
2. a relatively thin layer of vari-textured gabbronorite,
3. a thicker sequence of semi-nodular-textured leucogabbronorite, and
4. a thick-sequence of nodular-textured anorthosite and leucogabbronorite.

This stratigraphic succession is also observed immediately to the south of Goulding Lake and at Gallo Exploration's Site 3 and Site 5 (Figures 3 and 4). The aphyric diabase is correlative with the post-East Bull Lake intrusion dike suite, whereas the glomeroporphyritic diabase breccia is a probable correlate of the porphyry diabase feeder dikes (unit 6b, Figure 3). The diabase breccia is best exposed in the southeastern corner of the intrusion. It is heterolithic, containing subrounded fragments of anorthositic and gabbroic rocks that were probably derived from the East Bull Lake intrusion, in addition to Algoman granitic clasts. The vari-textured gabbronorite and the inclusion-bearing leucogabbronorite units are generally analogous to rocks from the base of the Anorthosite Subzone from the Moon Lake area (see above). However, the inclusion-bearing unit at Nodule Hill is generally more pyroxene-rich, comprising mainly anorthositic gabbronorite. It typically displays a semi-nodular texture, containing up to 20% irregularly shaped plagioclase aggregates which locally display pull-apart structures (Photo 3). These features suggest that some of the aggregates are exotic and may have been derived from erosion of the overlying nodular-textured anorthosite/leucogabbronorite by a later pulse of magma. The nodular-textured anorthositic unit contains regularly shaped rounded to five- or six-sided plagioclase aggregates, set in a discontinuous network of coarse-grained to pegmatitic gabbronorite to pyroxenite (Photo 4). The nodules appear to represent clusters of cumulus plagioclase, and the matrix, the crystallization product of mafic to ultramafic residual liquids trapped between the nodules. The nodules are generally closely spaced and account for 50% to 90% of the volume of the rock.

Exposures of the Anorthosite Subzone occurring immediately to the west of South Lake (Figure 4) and to the west of Moon Lake (Figure 3) display a relatively simple stratigraphy in comparison to the previously described type sections (Figure 5). As observed elsewhere, the contact sulphide mineralization is hosted by inclusion-bearing anorthosite to leucogabbronorite. The base of the Anorthosite Subzone at these localities is separated from the Archean basement by diabase, including aphyric dikes and/or plagioclase-phyric intrusive breccias.

In most parts of the East Bull Lake intrusion, the Anorthosite Subzone grades upward into the more massive and texturally homogeneous Leucogabbronorite Subzone (Figure 5), which, in turn, is overlain by the Rhythmically-Layered Gabbronorite Zone (Peck and James 1991). Whereas the base of the intrusion is characterized by heterogeneous, and commonly chaotic fabrics suggestive of turbulence, the overlying cumulates display regular modal layers and consis-

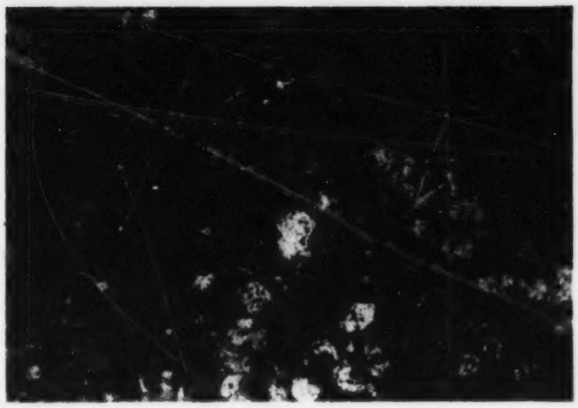

Photo 3. Semi-nodular-textured leucogabbronorite, Nodule Pond area, East Bull lake intrusion.

Photo 4. Nodular-textured anorthosite from the Nodule Pond area, East Bull Lake intrusion.

tent textures indicative of a more stable environment. The origin of the textural complexity observed in the vicinity of the contact sulphide mineralization has important implications with respect to the distribution of both the PGE and base metals contained therein, and will be the focus of future research.

Sulphide Mineralization

The distribution of sulphides within the zone of contact mineralization is quite erratic. The sulphides are typically concentrated into lenses that range from a few centimetres to greater than one metre in length. The abundance of sulphide in these zones varies from less than 1% to 10%. The zones are not restricted to any particular rock type within the Anorthosite Subzone, although the pyroxenite inclusions are nearly always mineralized. The mineralization comprises pyrrhotite and chalcopyrite, with lesser pentlandite. The relative proportions of the two principal sulphide phases are quite variable, but on average, they are present in approximately equal abundance. Pyrite is only developed in gossans from the Border Zone. The sulphide minerals occur both as irregularly shaped clots up to 2 to 3 cm in maximum dimension, and as finer grained disseminations.

In general, the total amount of sulphide present in a given outcrop from the zone of contact mineralization is less than 1%. The sulphides are commonly associated with distinct postcumulus pyroxene and blue to purple quartz, and locally, with magnetite. The primary texture and mineralogy of the host rocks has been partially to strongly obscured by greenschist-facies metamorphism. Pyroxenes are replaced by tremolite, actinolite, hornblende, anthophyllite and talc, whereas plagioclase is replaced by chlorite and saussurite, and is locally rimmed by blue-green amphibole and/or biotite. The rocks commonly display evidence of grain size reduction.

The sulphide minerals were recrystallized and remobilized to varying degrees during metamorphism. In the least-altered specimens, the sulphides have textures similar to the postcumulus pyroxenes, and form coarse-grained postcumulus aggregates which partially enclose adjacent silicate minerals (e.g. Gallo Exploration's Site 3). However, in more altered samples, the sulphide minerals are finer grained and more evenly disseminated through the rock, often forming rims around secondary silicate minerals. In strongly jointed samples, scaly, secondary sulphide mineralization is commonly developed along joint-planes and in irregular fractures. Preliminary observations suggest that the contact sulphide mineralization originated from a combination of the following processes:

1. assimilation of quartz by the parental mafic magmas owing to partial melting of Algoman granitic inclusions,

2. turbulent interaction between partially consolidated anorthositic cumulates and a later pulse of mafic magma,

3. fractional crystallization of cumulus plagioclase from the parental magma(s), and concentration of chalcophile elements, Mg, Fe, Si and volatiles into residual liquids, and

4. transport of chalcophile metals with dissolved volatile components in residual liquids.

PGE, Cu and Ni Abundances

Table 1 presents previously unpublished Pt, Pd, Au, Cu and Ni determinations for samples of contact sulphide mineralization from the East Bull Lake intrusion. The data represent the most highly enriched specimens from a suite of over 100 analyzed samples collected from the zone of contact sulphide mineralization, predominantly from the Moon Lake grid (Figure 3) and from the area lying between Parisien Lake and Gallo Exploration's Site 5 (Figures 3 and 4). The results include data from the current study and analyses provided by Gallo Exploration. Data for an additional 100 to 150 samples from this zone, together with the results from the lithogeochemical survey of the study area, will be released in a forthcoming open file report.

The erratic distribution of the sulphide mineralization has made representative sampling extremely difficult. All of the samples collected are grab or chip samples from outcrop, and it is clear that a more detailed and systematic approach to sampling (see below) is required before a thorough understanding of the PGE distribution can be advanced. However, our preliminary data indicate several important features of the PGE and base metal tenor of the contact sulphide mineralization. The maximum precious metal concentration observed to date is 6 ppm Pt + Pd + Au (Table 1). Greater than 90% of the approximately 100 samples analyzed during the current investigation contain in excess of 0.5 ppm Pt + Pd + Au, and many samples contain between 1 and 3 ppm Pt + Pd + Au (Table 1). The samples commonly contain between 0.4 and 0.7% combined Cu + Ni. The mineralization is characterized by having Pd:Pt ratios between 1:1 and 5:1, low Au abundances (commonly less than 200 ppb), and high, but extremely variable, Cu to Ni ratios (commonly between 2:1 to 10:1; *see* Table 1). The contact sulphide mineralization is more strongly enriched in PGE per unit volume of sulphide than is the hydrothermal mineralization from the Parisien Lake deformation zone (*see* Table 1; *see also* Peck and James 1991). Preliminary total PGE determinations for samples from both types of sulphide mineralization, provided by Gallo Exploration, indicate that the contact mineralization is also distinguished from the hydrothermal occurrences by having much lower Pt:Rh (1.5:1 to 16.3:1) and Pd:Ir (124:1 to 425:1) ratios (E. Gallo, Gallo Exploration Services Inc., personal communication, 1991).

The data indicate that the contact sulphide mineralization locally contains economically significant PGE mineralization. Peck and James (1991) report a strong correlation between total PGE abundance and the concentration of other chalcophile elements, including Cu, Ni, Co, Se and Bi. However, more recent results suggest that there is a strong spatial control on the PGE grades that supersedes any simple correlation with total sulphide abundance. The specific factors governing the variations in the Pd:Pt ratios and the total PGE tenor are not presently known, but may emerge through additional petrological and geochemical research planned for the remainder of the current project. Particular emphasis will be placed on assessing the role of crustal assimilation, magma mixing, fractional crystallization and volatile transport in the distribution of base and precious metals within the zone of contact sulphide mineralization.

EXPLORATION GUIDELINES

In order to accurately assess the economic potential of the zone of contact sulphide mineralization, we recommend that a detailed surface exploration program of the known occurrences (Figures 3 and 4) be undertaken. The program should initially involve detailed mapping at a scale no smaller than 1:1000, using cut grid lines. This should be followed by stripping of selected outcrops and, where necessary, trenching to expose bedrock, leading up to very detailed mapping and systematic sampling. Sampling of the zone poses the major problem to the assessment of its economic potential. We suggest that closely spaced channel sampling or sampling of a grid at 10 cm intervals using a hand-held diamond drill would provide the best approach. We have already identified several prospective localities where this type of sampling is warranted (e.g., Moon Lake area). Owing to the low total sulphide abundance, geophysical surveys will have limited use in defining the mineralized zone, but in the most intensely mineralized localities (e.g., Moon Lake area), induced polarization surveys may aid in defining the down-dip extent of the mineralization. Diamond drilling will provide detailed stratigraphical information and will define the subsurface distribution of the mineralized zone, as demonstrated in AECL drill hole EBL1 (Figure 3), in which the mineralized zone is intersected at a depth of 640 m. However, drilling is a costly and risky approach to sampling these occurrences, and is not recommended for grade control studies during the initial stages of exploration. The northern margin of the intrusion should also be examined in detail for contact sulphide mineralization, particularly immediately to the north of Bull Lake (Figure 3), where blue quartz-bearing leucogabbronorite, similar to rocks from the Border Zone exposed to the east of Moon Lake, was observed during the 1990 field season.

SUMMARY

Following the second year of field work in the current program, we have identified a mappable and laterally continuous zone containing disseminated, magmatic chalcopyrite + pyrrhotite + pentlandite mineralization along the southern margin of the East Bull Lake gabbro-anorthosite intrusion. Preliminary assay results indicate that the mineralization carries elevated concentrations of the PGE and gold, with a maximum of 6 ppm combined Pd + Pt + Au being observed to date. The emphasis of the current study will now shift toward detailed laboratory investigations, in order to further characterize the mineralization and to provide petrologic insight. The contact sulphide mineralization, together with structurally controlled massive Cu + Ni sulphide mineralization occurring along the Parisien Lake deformation zone, constitute the principal exploration targets in the study area. However, other sulphide occurrences are known from the East Bull Lake intrusion and the Nipissing (?) gabbroic intrusions occurring to the north. The economic potential of these areas is not known, but will be addressed in the forthcoming year.

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13. Project Unit 88–06. Eastward Tracing of the Patricia Showing—Hoodoo Prospect Deformation Zone, Northern Swayze Belt

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INTRODUCTION

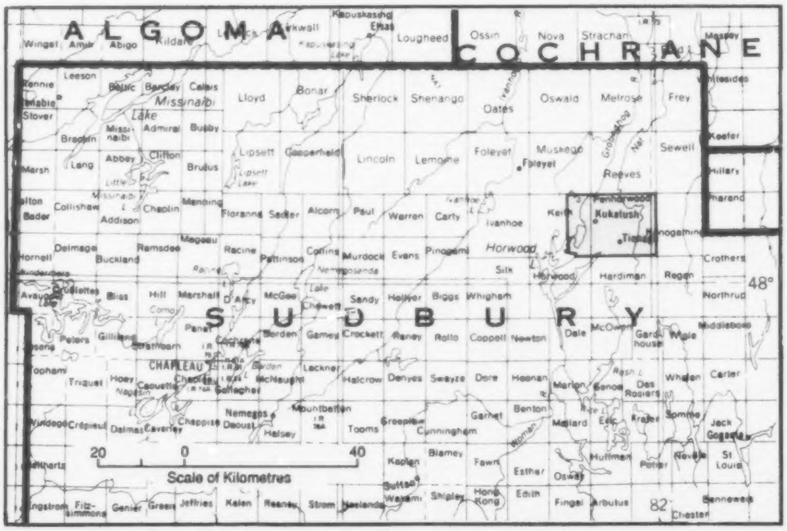
Detailed work completed last year in the Patricia showing—Hoodoo prospect area (PSHPA) of Keith Township (Siragusa 1990a), reconnaissance visits to other localities in eastern Keith Township (Siragusa 1990b, Figure 13.2), and interpretation of previous data by Prest (1951) and Milne (1972) led the author to suggest the existence of a broadly east-trending zone of deformation (KPZ) extending through Keith and Penhorwood townships (Siragusa 1990b). The segment of the KPZ exposed in the PSHPA is characterized by features, previously described in detail (Siragusa 1990b), comprising: 1) ubiquitous carbonatization of variable intensity; 2) development of dominantly ductile deformation; 3) complex folds; and 4) differences in volume and pattern of the associated quartz-carbonate veining, some of which are auriferous, depending on the intensity of deformation.

The objective of reconnaissance work carried out in 1991 (Figure 1) was to locate exposures of the KPZ east of the PSHPA using, as criteria, the general characteristics outlined above. Outcrop areas, recognized as exposures of the KPZ, were mapped at the scale of 1:100 and sampled for a lithogeochemical study aimed, primarily, to investigate the gold potential of the KPZ. The KPZ was located in three areas which, from east to west, are: 1) the banks of the Groundhog River close to the CN railway bridge (eastern Keith township); 2) an area adjacent to the West Branch Nat River (western Penhorwood Township); and 3) an area of eastern Penhorwood Township approximately 2 km west of the boundary between Penhorwood and Kenogaming townships (*see* Figure 2).

AREA 1: GROUNDHOG RIVER

Outcrops found on both sides of the Groundhog River are narrow and seldom traceable inland from the water's edge. The fissile nature of most of these outcrops has accelerated their degradation, and variable volumes of detached rock slabs occur adjacent to them.

On the west side of the river, sheared, pervasively carbonatized, east-striking, felsic metavolcanic rocks, dipping steeply to the north, are exposed 27 m west and 34 m north of the railway-bridge abutment at the water's edge. The outcrop


ALGOMA
COCHRANE
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Kapuskasing
Elsas
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Lougheed
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Strachan
Massey
Leeson
Barclay
Missinaibi Lake
Lloyd
Bonar
Sherlock
Shenango
Oates
Oswald
Melrose
Frey
Whitesides
Stover
Admiral
Busby
Keefer
Bradburn
Missinaibi
Abbey
Clifton
Lipsett
Lipsett Lake
Lincoln
Lemoine
Foleyet
Muskego
Groundhog
Nat
Sewell
Marsh
Lang
Brutus
Reeves
Hillary
Collishaw
Little Missinaibi L
Chaplin
Addison
Manning
Floranna
Sadler
Alcorn
Paul
Warren
Carty
Ivanhoe L
Ivanhoe
Keith
Penhorwood
Kukatush
Tionaga
Kenogaming
Bader
Delmage
Ramsdee
Mageau
Racine
Pattinson
Collins
Murdock
Evans
Pinogami
Horwood
Hornell
Buckland
Nemegosenda
Silk
Horwood L
Hardiman
Regan
Crothers
48°
Avaugour
Bliss
Hill
Marshall
D'Arcy
McGee
Chewett
Sandy
Hellyer
Biggs
Whigham
Northrup
Como L
Penet
Borden
Gamey
Crockett
Raney
Rollo
Coppell
Newton
Dale
McOwen
Gardhouse
Wigle
Middleboro
Peters
Gilliland
Cochrane
Lackner
Halcrow
Denyes
Swayze
Dore
Heenan
Marion
Genoa
Des Rosiers
Whalen
Carter
Topham
Triquet
Hoey
Nagasin
Caouette
CHAPLEAU
Chapleau
Borden
McNaught
Gallagher
Benton
Garnet
Mallard
Eric
Kraler
Somme
Jack
Gogama
Windego
Crépieul
Dalmas
Caverley
Chappise
Nemegos
Deoust
Halsey
Mountbatten
Tooms
Greenlaw
Cunningham
Woman
20
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40
Scale of Kilometres
Kaplan
Blamey
Fawn
Esther
Oswald
Huffman
Potier
Nevills
St Louis
Ingstrom
Fitzsimmons
Genier
Green
Jeffries
Kalen
Reaney
Strom
Sultan
Shipley
Hong Kong
Edith
Fingal
Arbutus
82°
Chester
Benneweis

Figure 1. Location map of study area, scale 1:1 584 000.

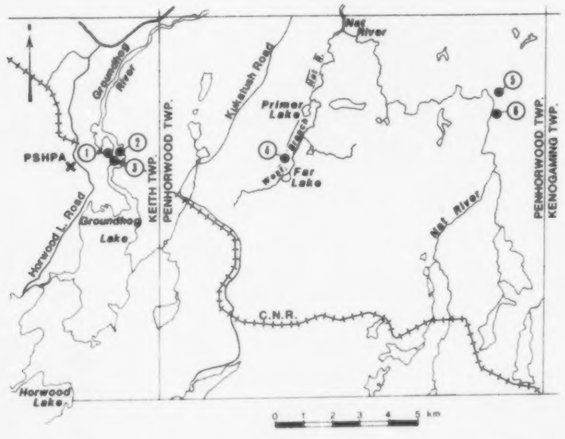

Figure 2. The full circles numbered 1 to 6 indicate the locations of the localities covered by mapping at the scale of 1:100. The cross shows the location of the Patricia showing–Hoodoo prospect area (PSHPA)

at this locality represents a cross-strike width of 13 m. Farther north, variably carbonatized, foliated to fissile, sheared outcrops are intermittently exposed over a distance corresponding to a cross-strike width of about 290 m. The metavolcanic rocks are intruded by a few pretectonic, felsic dikes similar to those found in the PSHPA (Siragusa 1990b). Tight, east-striking folding is indicated by a few metre-sized, Z-type folds, and by the locally curviplanar attitude of foliation and shear fractures. Closely spaced, millimetre- to centimetre-thick quartz-carbonate veinlets occur in some outcrops but, in general, quartz-carbonate veins are scarce. Compared to the metavolcanic rocks on the north side of the railway bridge, metabasalt and metaperidotite located 11 and 30 m to the south of the bridge, respectively, are much less carbonatized.

Outcrops on the east side of the river consist of felsic metavolcanic rocks intermittently exposed over a distance corresponding to a cross-strike width of 85 m. They have the same structural trend of the rocks directly along strike across the river and are similarly sheared and carbonatized. A bush traverse, approximately 300 m east of the Groundhog River, revealed the pyroclastic nature of these rocks, but no outcrops were found along other traverses, 2 and 2.8 km east of the river.

AREA 2: NAT RIVER

This steep outcrop area, exposed by recent exploration slightly west of the Nat River, comprises carbonatized ultramafic rocks. These are characterized by subvertical, dominantly east-striking, pervasive shearing; tight folds; and sets of discrete, straight to curviplanar shear fractures, most of which are subparallel to shearing. Polysutures, preserved in parts of the outcrop, resemble those of spinifex-bearing komatiite seen elsewhere (*see* Conclusions), suggesting that the rock is probably of volcanic origin.

The main outcrop includes an east-striking quartz vein which dips 60° to 70° to the south, has exposed strike-length of approximately 12 m and width of 1.2 to 2 m. Compared with the complex quartz veining observed elsewhere along the KPZ (Siragusa 1990b), this vein is unusual in its size, sharp contacts, and relatively consistent trend. Most of the rock, at some distance from the vein, is a soft talcose schist which locally contains pyrite disseminations and weathers to reddish-grey hues. The vein wall rocks, and particularly the hanging wall, are relatively hard due to pervasive silicification; they have an intense light-green colour (mariposite?) and are affected by pronounced gossan penetrating the rock for 1 or 2 cm. Weaker, yet still traceable, linear gossans occur also in the foot wall, a few metres from the quartz vein.

AREA 3: EASTERN PENHORWOOD TOWNSHIP

The KPZ exposures found here include 2 separate outcrop localities. The smaller locality is approximately 900 m north of the other, this distance corresponding to a cross-strike width of about 400 m. The existence of a low-strain subzone within this width is indicated by an isolated outcrop of relatively uncarbonatized metabasalt at a cross-strike distance of 80 m from the larger locality.

Both localities are similar to the PSHPA in lithology, widespread carbonatization, and in the complexity of structural features and associated quartz-carbonate veining. They are underlain by mafic volcanic rocks intruded by pretectonic, felsic dikes or sills. The state of preservation of the latter varies from variably fractured and/or offset units, showing sharp contact relationships, to tightly folded and distorted relicts poorly distinguishable from the reddish-brown chlorite-carbonate schists enclosing them. The least deformed units of these rocks are considerably thicker than those occurring in the PSHPA; in other words, their thickness increases eastward along the study area. This condition, and the proximity of these pretectonic dikes and/or sills to the felsic volcanic Hanrahan Lake Complex (Milne 1972), leave little doubt that these rocks are of subvolcanic origin.

The shearing trends northeastward and, particularly in the case of the larger outcrop locality, shows reversals of dip-direction. This is due to tight, northeast-trending folds having northeasterly through subhorizontal to southwesterly plunge. The folds are affected by numerous, essentially straight, quartz-filled tension fractures which are orthogonal to the shearing and have moderate to very shallow, northeasterly dips. The quartz veins filling these fractures seldom exceed the thickness of a few centimetres and represent a late stage of silica deposition. By contrast, earlier silica deposition comprises complex quartz-carbonate veins associated with mesoscopic folds and their auxiliary plications. As previously noted in the PSHPA, these are clearly related to ductility contrast between basalt and felsic subvolcanic intrusions. The outcrops of area 3 differ from those in the PSHPA in that the estimated volume of quartz, hosted collectively by the shallow-dipping tension fractures, exceeds that of the quartz associated with earlier deformation.

CONCLUSIONS

The PSHPA is structurally along strike of the Joburke Mine, a former producer of 512 kg of gold. After last year's field work, it was suggested that: 1) the Joburke Mine area and the PSHPA are part of a main, broadly east-trending, linear deformation zone (KPZ); and 2) such zone could extend to the area of western Penhorwood Township situated south of Primer Lake (Siragusa 1990b). The 1991 field work has confirmed that the KPZ occurs south of Primer Lake (*see* Figure 2, location 4) and, in addition, has revealed that the KPZ extends at least as far east as eastern Penhorwood Township (*see* Figure 2, locations 5 and 6) This represents a distance of about 16 km from the PSHPA.

Felsic metavolcanic units occur north and south of the pillowed metabasalt underlying the PSHPA (Siragusa 1990b, Figure 13-2, localities 1 and 3), but the stripping done in the area did not extend to the contact zones of the metabasalt with the felsic metavolcanic units. The KPZ exposures in the Groundhog River area (area 1) include the contact zone of the metabasalt with the northern felsic metavolcanic unit, and the cross-strike width of sheared and carbonatized rocks is considerably wider than in the PSHPA.

The metavolcanic rocks affected by the KPZ in the PSHPA and the Groundhog River area are part of an east-trending, north-dipping and north-facing metavolcanic sequence overlain by iron formation. The latter forms a prominent unit exposed on the banks of the Groundhog River, as well east and west of the river (Prest 1951, ODM Map 1950-4). Komatiite with well-preserved spinifex texture, occurring on the north side of the iron formation (Horwood Lake Road), indicates that, in eastern Keith Township, the KPZ is mainly confined to the stratigraphic section below (i.e., south of) the iron formation. Because of this, the area extending from the PSHPA to the Groundhog River, and from the iron formation to about 1500 m south of it, may warrant exploration.

The outcrop area in the vicinity of the West Branch Nat River (area 2) differs from the KPZ exposures in eastern Keith and eastern Penhorwood townships in having an ultramafic composition and in the width of the quartz vein found at this locality. It is uncertain if such width is dependent on conditions characteristic of this locality, or whether it reflects lithologically-controlled conditions that may be repeated at other localities underlain by the carbonatized ultramafic rocks of the Nat River area. Depending on the results of assay data, further work in the area may be desirable.

One item of interest, in a broad tectonic context, is the relationship between the KPZ and a main structure of eastern Penhorwood township reported by Milne (1972). This latter structure consists of an east-trending and west-plunging antiform, the core of which consists of felsic metavolcanic rocks rimmed by a thin unit of iron formation (*see* Milne 1972, ODM Map 2231). The iron formation and felsic volcanic rocks at the rim of the structure, which according to this author is an (true) anticline, are exposed in a trench located approximately 600 m west of the KPZ outcrops covered by the present mapping. The fact that the rocks exposed in the trench do not show the structural complexity and carbonatization characteristic of the nearby KPZ outcrops may not be, per se, particularly significant (i.e., it may simply reflect the presence of a low-strain subzone). However, when this observation is added to the fact that in the outcrops of the KPZ the shearing trends northeast, there is a clear indication that the KPZ does not transgress the anticline. In other words, close to the apex of the anticline, the KPZ deflects from its easterly trend (western Penhorwood township) to a northeasterly trend so as to parallel the main, northeast-trending limb of the anticline. This condition suggests that the KPZ is unlikely to postdate the major tectonism which resulted in the development of the anticline.

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14. Project Unit 91–09. Geology of Hoyle and Gowan Townships, District of Cochrane

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INTRODUCTION

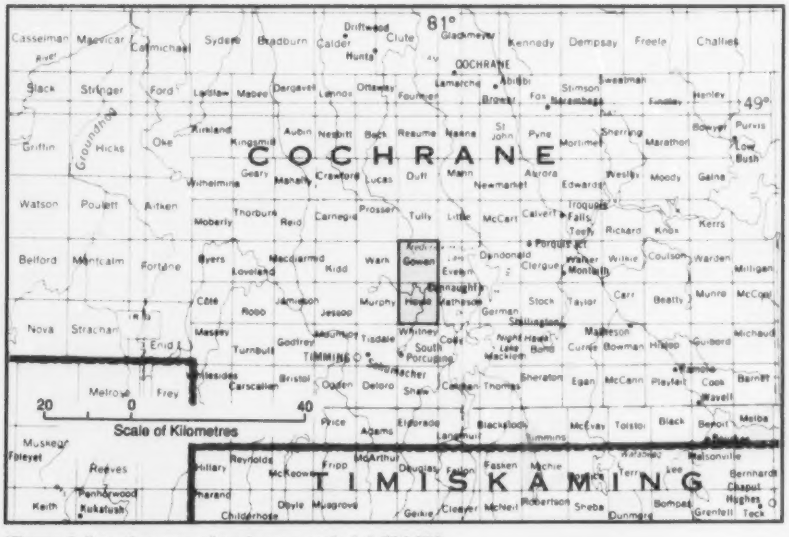
Hoyle and Gowan townships are bounded by latitudes 48°32'30"N and 48°42'30"N, and by longitudes 81°05'W and 81°12'W in the District of Cochrane, northeastern Ontario (Figure 1). The southern part of Hoyle Township, approximately 18 km northeast of the city of Timmins is accessible by road to the Bell Creek and Hoyle Pond gold mines. The northern half of Hoyle Township and all of Gowan Township are most easily accessible by helicopter in summer and/or by snow machine in winter.

MINERAL EXPLORATION

Mineral exploration in both townships is hampered by both extensive overburden and the amount of patented land which makes property acquisition difficult.

Rose (1924) indicated that Hoyle Township was prospected for gold in the early 1900s; however, no important discoveries were reported, and exploration activity was relatively low until the discovery of the Kidd Creek base metal deposit was made in 1964. At this time, several individuals and companies explored various parts of the township aided by magnetic and electromagnetic surveys. The International Nickel Company Limited discovered gold mineralization at this time in the southern part of Hoyle Township and this later became part of the Hoyle Pond and Owl Creek mines. In the early 1980s, continued, intensive exploration resulted in the discovery of gold mineralization in the southwestern part of Hoyle Township by Canamax Resources Incorporated whose discovery was later developed into the Bell Creek Mine. Several parcels of land are currently being explored in that township.

There is no record of mineral exploration in Gowan Township until after the discovery of the Kidd Creek base metal deposit in 1964. At this time, several companies carried out geophysical surveys which delineated several conductive zones. Diamond-drill testing of some of these conductors failed to discover either significant base or precious metal mineralization. In 1975, exploration by Alamo Petroleum Limited in the east and central part of Gowan Township resulted in the discovery of copper and zinc mineralization hosted in ultramafic schists and intrusions where they are in close spatial association with felsic flows and quartz porphyritic intrusions. Subsequent work, in 1977, by Newmont Mining Corporation of Canada Limited confirmed the base metal mineralization but it did not find sufficient


81°
49°
COCHRANE
C O C H R A N E
T I M I S K A M I N G
Gowen
Hoyle
TIMMINS
20
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Casselman
Calder
Clute
Kennedy
Dempsay
Freele
Challies
Stimson
Pyne
Mortimer
Marathon
Watson
Poulett
Aitken
Moberly
Thorburn
Reid
Carnegie
Prosser
Tully
Little
McCart
Calvert
Belford
Montcalm
Fortune
Loveland
Kidd
Wark
Evelyn
Dundonald
Clergue
Walker
Nova
Strachan
Enid
Turnbull
Godfrey
Jamieson
Jessop
Murphy
Tisdale
Whitney
Carr
Beatty
Munro
Stock
Taylor
Matheson
Bowman
Hislop
Guibord
Michaud
Carscallen
Bristol
Ogden
Deloro
Shaw
Thomas
Sheraton
Egan
McCann
Playfair
Melrose
Frey
Price
Adams
Eldorado
Blackstock
Langmuir
McEvay
Tolstoi
Black
Benoit
Reeves
Keith
Hillary
Reynolds
McKeown
Fripp
McArthur
Douglas
Fallon
Fasken
Michie
Teck

Figure 1. Location map of study area, scale 1:1 584 000.

quantities to justify further work. Several mining claims were in good standing at the time of writing.

GENERAL GEOLOGY

Introduction

The geological-mapping methodology employed by this project to map Hoyle and Gowan townships was not typical of standard methodologies used in typical Ontario Geological Survey projects. As exposure is less than 1%, the project relied heavily on the synthesis of published assessment-work data and the integration of airborne magnetic and electromagnetic surveys (OGS 1988a, 1988b; Barlow 1988a, 1988b, 1988c). Diamond-drill core stored at the Drill Core Library, Ministry of Northern Development and Mines, Timmins, and drill core made available to the author by mining and exploration companies were examined; these data together with mapping of the available outcrops provided the basis for interpretation of the assessment and geophysical data. Reverse-circulation overburden drilling has been carried out by several companies over most of the map area, and bedrock chips made available by some of these companies were examined.

Metavolcanic Rocks

Ultramafic, mafic, intermediate and felsic metavolcanic rocks occur in the map area. Ultramafic metavolcanic rocks occur as outcrops in southern Hoyle Township (Figure 2) where they are brown to dark-green weathering and contain polysuturing and/or spinifex textures. Ultramafic schist in the vicinity of the Bell Creek Mine shaft weathers brown, is highly carbonatized and contains various amounts of quartz veining, bright-green mica and pyrite. Ultramafic rocks in Hoyle Township, observed by the author in diamond-drill core, are highly carbonatized and rarely retain distinctive primary flow features. These rocks are grey to dark green, nonmagnetic and commonly contain minor amounts of green mica. Trace-element geochemistry carried out by exploration companies shows high nickel and chromium levels indicative of ultramafic rocks. Ultramafic flows are reported from diamond-drill logs in Gowan Township. Ultramafic flows with spinifex, and rarely with polysuturing, are reported to underlie, in part, the central part of the township. The flows are spatially and probably genetically associated with ultramafic intrusions reported in the same area.

Mafic metavolcanic rocks are widespread in southern Hoyle Township and in the southern and eastern parts of Gowan Township. Mafic metavolcanic outcrops in southern Hoyle Township are green, greenish grey or grey weathering and are massive, pillowed, pillow brecciated and schistose. Green, massive flows are commonly medium grained and leucoxene bearing which is inferred to signify a high-iron tholeiitic affinity. Greyish green or grey-weathering, massive flows are commonly fine grained to aphanitic and are inferred to represent high-magnesium tholeiites. No systematic variation between flow types was detected in outcrop or in diamond-drill core. Many of the flows are pillowed with a poorly to well-developed flow-top breccia. These units are commonly amygdaloidal with quartz and carbonate filled amygdules up to 7 mm diameter and comprising up to 20% of the rock.

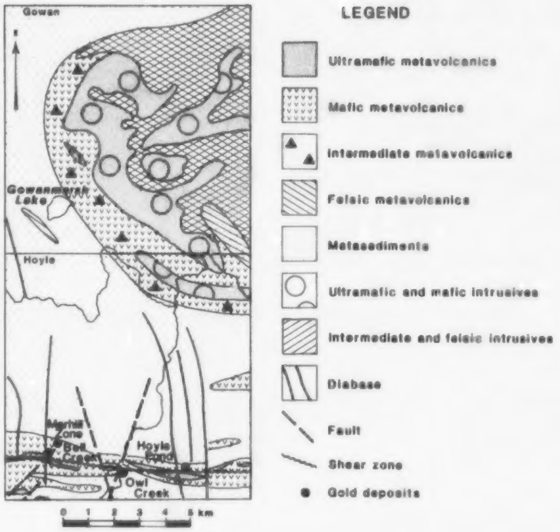

Figure 2. General geology of Hoyle and Gowan townships.

Variolitic mafic flows are common in Hoyle Township. In the eastern part of Hoyle Township, variolitic pillowed flows are exposed at the Kidd Creek metallurgical site and along the eastern side of the Kidd Creek Mine's tailings pond. In both places, varioles cluster in the centre of pillows and are commonly coalesced. Individual varioles, up to 7 mm in diameter, were observed close to pillow selvages. The same morphology was observed in diamond-drill core throughout the southern part of Hoyle Township. Some variolitic, massive flows observed in drill core display small, oval plagioclase spherules (1 to 2 mm diameter) that occur individually as either coalesced aggregates or, rarely, dendritic arrays. This morphology is commonly closely spatially associated with ultramafic units.

At one place, near the Bell Creek Mine's headframe, dark-green mafic tuff was observed.

Mafic metavolcanic rocks in Gowan Township are reported in overburden-drill and diamond-drill logs. The few samples of assessment-work drill core that are available at the Timmins Drill Core Library comprise samples identified as green, fine-grained, massive and pillowed flows. These flows have generally been recrystallized by chlorite and amphibole and are inferred to be iron tholeiites. Varioles were observed in a piece of drill core obtained from the central part of the township.

Intermediate metavolcanic rocks are reported from diamond- drill logs describing holes drilled in both northern Hoyle Township and in various locations in Gowan Township. These rocks are variously described as "andesite" flows and "intermediate" tuff; however, the drill-core samples examined by the author were interpreted to be either mafic flows or feldspar-porphyry dikes.

Felsic metavolcanic rocks occur in outcrop and in diamond-drill core in Gowan Township. Two large outcrops of felsic tuff and schist occur west of Gowanmarsh Lake in southwestern Gowan Township. The tuff is white to grey weathering, quartz rich and, locally, it is interbedded with minor amounts of wacke. Quartz-porphyry dikes were locally intruded into the tuff. The tuff is sheared along the northeastern edges of the outcrops and here a quartz-sericite schist that locally contains carbonate and pyrite is present. Felsic metavolcanic rocks observed in drill core consist of flow-laminated rhyolite; massive, aphanitic and quartz-porphyritic rhyolite; felsic tuff; flow and pyroclastic breccia and quartz-sericite schist. These rocks are pink, white and grey and locally contain from trace to 10% pyrite, chalcopyrite and sphalerite. Felsic metavolcanic rocks in the central part of Gowan Township are spatially associated with megacrystic quartz-porphyry intrusions and with ultramafic flows and intrusions. This essentially bimodal distribution of felsic and ultramafic lithologies is observed throughout the Timmins area and is most notable at the Kidd Creek base metal mine approximately 19 km to the west.

Metasedimentary Rocks

Metasedimentary rocks comprising wacke, siltstone, mudstone and graphitic and/or pyritic mudstone underlie the central and northern parts of Hoyle Township and the eastern part of Gowan Township; they are interlayered with mafic metavolcanic rocks in the southern part of Hoyle Township. These metasedimentary rocks are grey, greyish green and black and contain many primary features such as grain gradation, load casts, small scour marks and "ripped-up" mud clasts indicative of turbidity-current deposition. Wackes are composed of fine- to very coarse-grained sand with a high proportion (greater than 50%) of feldspar and lithic, volcanic fragments. Wacke beds vary between 1 mm and 1 m in thickness and are volumetrically the most abundant metasedimentary rock in the map area. Grain gradation is common in wacke beds; however, massive beds do occur, especially in the thickest and thinest beds.

Dark-grey or black siltstone is volumetrically minor in the metasedimentary sequence and commonly occupies the top of turbidites as the "E" division of the Bouma sequence. Siltstone is most abundant in those metasedimentary rocks which are interlayered with mafic metavolcanic rocks in southern Hoyle Township.

Mudstone and graphitic and/or pyritic mudstone units occur throughout the metasedimentary rocks and occur locally between mafic metavolcanic flows. Grey to dark-grey mudstones commonly form either thin beds or laminae at the top of turbidites and interpreted to be the "D" and "E" subdivisions of the Bouma sequence. Mudstone commonly forms less than 5% of the metasedimentary sequence; however, it may locally comprise up to 35% of the beds over thicknesses of 5 m in drill core.

Graphitic and/or pyritic mudstone is a distinctive rock type exposed only in drill core in the map area. These units comprise laminated to thinly bedded mudstone impregnated with graphite and amorphous carbon (Downes et al. 1984) and are commonly interbedded and laminated with fine-grained pyrite and concretionary pyrite nodules up to 1 cm in diameter. These units are correlated with the airborne electromagnetic anomalies (OGS 1988a) in Hoyle Township and with some of the electromagnetic anomalies in southeastern Gowan Township (OGS 1988b). The graphitic and/or pyritic mudstones serve as marker horizons in southern Hoyle Township and are economically important as they occur on both the hanging wall and the foot wall of the Owl Creek gold deposit. Remobilized carbon, derived from these mudstones, is believed to have played a role in the gold-mineralization event (Downes et al. 1984; Wilson and Rucklidge, in press). Carbon-alteration zones in metavolcanic rocks—referred to as "grey zones" by mine geologists—are excellent exploration targets for gold mineralization.

Ultramafic and Mafic Intrusive Rocks

Ultramafic and mafic intrusive rocks are composed of serpentinite (peridotite), talc-chlorite-carbonate schist, gabbro, lamprophyre, gabbro and diabase dikes. In southern Hoyle Township, ultramafic rocks that contain either polysuturing or spinifex textures are interpreted as flows. Pervasively altered talc-chlorite-carbonate schist, without discernable primary features, commonly attains thicknesses of several hundred metres in some areas and may represent ultramafic intrusions.

Massive serpentinite- and talc-altered intrusions (over 300 m thick) are present in the central part of Gowan Township and are correlated with large magnetic highs (OGS 1988b). These units, as observed in drill core, are dark green to dark grey, magnetic and are generally featureless. Locally, large (up to 1 cm in diameter), euhedral carbonate and magnesite porphyroblasts occur. Although these units are vertically and laterally contiguous with spinifex-textured ultramafic flows, they are interpreted as intrusions because of their thickness and absence of primary features. The ultramafic rocks display an intimate spatial association with felsic metavolcanic and felsic intrusive rocks in the same area. Commonly, ultramafic and felsic units are repeated over narrow intervals (tens of meters) within one diamond-drill hole. Where this occurs, as in the central part of Gowan Township, sulphides commonly accompany the ultramafic rocks at or near the contacts with the felsic units. In one place, the concentration of sulphides included chalcopyrite and sphalerite in subeconomic quantities (*see* Economic Geology).

Gabbro is subordinate in the map area. This rock type was not observed by the author but is reported in diamond-drill holes from northeastern Hoyle Township and in Gowan Township.

Lamprophyre dikes occur in southwestern Hoyle Township on the Canamax Resources Incorporated property at the Marhill gold zone. Here, two north- to northwest-trending, narrow (15 cm wide) dikes were observed to be folded by an easterly trending foliation. These dikes were extensively carbonatized and show recessive-weathering structure. Dark-green amphiboles were the only primary minerals observed in the dikes.

A lamprophyre dike was observed in close spatial association with quartz veins in old trenches excavated approximately 1500 m southwest of the Bell Creek Mine headframe. The dike is poorly exposed and contains coarse-grained biotite crystals in a plagiclase-quartz-carbonate groundmass.

A northwest-trending gabbroic dike (50 m wide) was observed to intrude clastic metasedimentary rocks in northwestern Hoyle Township. The dike has a 60 to 70 cm wide chilled margin and a medium-grained plagioclase-rich interior. The dike is inferred to be Archean in age because it is foliated parallel to the regional northwest strike of the units and because it is metamorphosed to greenschist facies as indicated by saussuritized feldspars and the development of chlorite in the mafic minerals.

Neoarchean to Paleoproterozoic diabase dikes intruded all lithologies in the map area. These dikes trend north to northwest, are dark green, medium grained and magnetic. Green and white plagioclase phenocrysts are common but not abundant in the dikes (commonly less than 5%). The dikes are easily traced in overburden-covered areas by their magnetic expressions and are known to crosscut stratigraphy and ore zones in the Hoyle Pond and Bell Creek mines.

Felsic Intrusive Rocks

Felsic intrusive rocks are composed predominantly of quartz-feldspar porphyry with various proportions of quartz porphyry, feldspar porphyry, related aplite dikes and very minor granodiorite. For the most part, these rocks are restricted to the central part of Gowan Township; however, a feldspar-porphyry dike was observed in 1 diamond-drill hole sited southeast of the Hoyle Pond Mine.

In Gowan Township, a distinctive, white to buff quartz-feldspar porphyry occurs in a close spatial relationship with ultramafic intrusions. The quartz porphyry contains large (up to 2 cm in diameter) quartz phenocrysts, which commonly contain inclusions of a black mineral (possibly chlorite), and these lie in a white sericitic groundmass. Although quartz-feldspar porphyry is the predominant rock type, the intrusion varies in composition between white quartz porphyry and grey feldspar porphyry end members. Mafic-mineral content is generally less than 10%. The mafic minerals are chlorite and biotite with very minor amounts of amphibole. Sulphides, predominantly pyrite with lesser chalcopyrite and sphalerite, locally comprise up to 5% of the rock and, rarely, magnetite is present. In many places, the rock is foliated and moderately sheared to a quartz-sericite schist. Locally, the rock is aphanitic and appears flow-like or tuffaceous.

STRATIGRAPHY

The metavolcanic rocks in southern Hoyle Township have been correlated with the lower part of the Tisdale assemblage (Group) (Kent 1990; Labine 1990; Fyon and Jackson 1990). Ultramafic and mafic flows are typical of the lowermost unit (Pyke 1982, formation IV) whereas the variolitic flows and iron tholeiites are most commonly associated with the middle unit (Pyke 1982, formation V).

The turbiditic metasedimentary rocks, including the graphitic and/or pyritic mudstones in Hoyle Township, are correlated with the Hoyle assemblage (Fyon and Jackson 1990). These rocks are interlayered with metavolcanic flows of the Tisdale assemblage and contact relationships are well preserved in drill core where the units appear to be conformable. In many diamond-drill holes sited south of the Bell Creek Mine, pillow breccia with a hyaloclastite matrix passes upwards into breccia with a carbonaceous matrix which in turn passes into carbonaceous and/or pyritic mudstone. The same sequence was observed in 1 drill hole northeast of the mine and indicates that both the metasedimentary and metavolcanic rocks are stratigraphically conformable in this area.

It is inferred that the metasedimentary rocks in Gowan Township are also part of the Hoyle assemblage as they are contiguous with the metasedimentary rocks in Hoyle Township. The stratigraphic relationship of these units with the metavolcanic rocks in Gowan Township is not clear. Contacts are not exposed at surface and only limited diamond drilling has been done. In these few drill holes, it appears that the metasedimentary rocks conformably overlie mafic and intermediate metavolcanic units and are interstratified with felsic tuff and flows.

The metavolcanic and the ultramafic and felsic intrusive rocks in Gowan Township are correlated with the Kidd–Munro assemblage (Fyon and Jackson 1990). This correlation is based on the spatial association of the rocks with other units of the assemblage and the composition of the rock units which are generally the same as the Kidd–Munro assemblage. This assemblage hosts the Kidd Creek base metal mine, and rock units in the map area represent a good exploration environment.

STRUCTURE AND METAMORPHISM

The lack of surface exposure hampers structural interpretation of the map area; nevertheless, several observations were made in the available outcrop and in diamond-drill core. Throughout the map area, a foliation, oriented semiparallel to bedding and lithological contacts, is developed. This foliation varies from weak to moderate intensity with the strongest development noted in the graphitic- and/or pyritic-mudstone units. At several places in diamond-drill core, it was noted that slickensides and polished surfaces were developed in the graphitic mudstones indicating movement had occurred along the bedding planes. At a few outcrop places, this foliation and the bedding were observed to be crosscut by a second foliation striking approximately 80°, in southern Hoyle Township, and approximately 100°, in southern Gowan Township. Reversals in stratigraphic facing in turbidites observed in both outcrop and diamond-drill core, together with the interpretation of the airborne magnetic data (OGS 1988a, 1988b), indicate that the metasedimentary rocks are folded about west- to northwest-trending axes. Stratigraphic-facing reversals were not observed in the metavolcanic rocks; however, it is assumed that they are folded, if only locally.

Although the structural relationships at all three mine sites in southern Hoyle Township are complex, there are common features observed in each area. At all three mines, there is a planar shear fabric oriented at 080±10° accompanied by east- to southeast- plunging, extensional mineral lineations. Small-scale step faults, mineral lineations, rotated quartz veins and pressure shadows on concretionary pyrite indicate that north-side-up vertical movement occurred on the shear fabric. This shear fabric appears to be the youngest as it is axial planar to the folded quartz veins and it sinistrally offsets older planar features in the mine areas and throughout the map area. The Bell Creek gold zone is localized along the lithological contact between ultramafic and basaltic rocks within the well-developed shear zone striking 080°. The 080° fabric is less well developed away from the mine sites and where present is characterized by narrow (less than 1 m wide), discrete shear zones or, more commonly, by a closely spaced foliation.

In several outcrops throughout Hoyle Township, a planar foliation oriented 060±10° is commonly developed. Northeast-plunging lineations and small-scale-fold axes accompany this fabric. Small-scale offsets and fold asymmetry generally indicate that sinistral movement occurred along these foliation planes. This fabric localizes the bulk of the high-grade gold mineralization at the Bell Creek, Hoyle Pond and Owl Creek deposits. Distinct, dark-grey, carbon-bearing alteration zones, with or without central quartz veins, are referred to as "grey zones" in the mines and many are controlled by the 060° fabric. The 080° shear fabric commonly cuts the 060° fabric; however, at the Bell Creek Mine, the reverse is observed (Eugene Kent, Mine Geologist, Canamax Resources Incorporated, personal communication, 1991).

A third planar element, oriented at 110±10°, is locally developed. The North Zone "A" Horizon and the North Zone "B" Horizon at the Bell Creek Mine are west-northwest-trending as are lithological units in the Owl Creek Mine area. Elsewhere, southeast-plunging mineral and extensional lineations are locally developed.

It is possible that these three structural elements are related to the development of an easterly trending shear zone extending through the southern part of Hoyle Township; moreover, they may represent the extension of the Destor–Porcupine Fault or a splay of that fault through the map area.

Structural relationships in Gowan Township are poorly constrained. Stratigraphic facings observed in outcrop and noted in diamond-drill logs indicate that rock units in the southern part of the township are folded about northwest-trending axes. Locally well-developed, northwest-trending, sinistral shear zones are also present. The central part of the township is underlain by ultramafic and felsic subvolcanic intrusions and flows, and airborne magnetic data indicates that complex folding of these units has occurred.

A number of late, brittle to brittle-ductile faults have cut all previous structures and lithologies. These are best documented in the southern part of Hoyle Township where 3 separate trends are recognized. North-northeast- to northeast-trending faults generally display a dextral offset of units. North-northwest- to northwest-trending faults generally display a sinistral offset of units, and north-trending faults display vertical and dextral offsetting. Diabase dikes commonly occupy the north- and northwest-trending faults. These late faults are best observed in drill core and are most important immediately west of the Owl Creek open pit where they appear to have displaced part of the deposit.

Most of the rocks in Hoyle Township have attained low-grade greenschist-facies metamorphism. Chlorite, albite and, rarely, epidote are common metamorphic minerals in mafic metavolcanic rocks. Talc and amphibole are common in ultramafic units, and chlorite, with or without biotite, is characteristic of the metasedimentary rocks. In the northern part of Hoyle Township and in most of Gowan Township, metasedimentary rocks are characterized by porphyroblastic biotite indicating that higher grades of metamorphism have affected these rocks. It is possible that these rocks have undergone contact metamoprhism as they are in close proximity to the ultramafic and felsic intrusions in Gowan Township.

ECONOMIC GEOLOGY

Gold occurs in southern Hoyle Township in sufficient quantities and grade to be commercially extracted by the Bell Creek, Hoyle Pond and, since 1990, the Owl Creek mines. Gold mineralization is structurally controlled (*see* above) and occurs in three predominant forms. Most of the gold at the Hoyle Pond and Owl Creek mines and at the North "A" and "B" horizons at the Bell Creek Mine is hosted along the selvages of quartz veins and wall rocks, or in styolitic fractures, commonly with hydromuscovite, within quartz veins (Labine 1990; Kent 1990). Gold also occurs as inclusions within fine-grained pyrite at the Owl Creek Mine (Coad et al. 1986), in sulphides in the Bell Creek zone and in sulphide-bearing wall rock at the North "A" and "B" horizons at the Bell Creek Mine (Kent 1990). Gold associated with amorphous carbon occurs as refractory ore at all three mines and has been discussed by Downes et al. (1984) and Wilson and Rucklidge (in press).

Chlorite, sericite-carbonate alteration and silicification in the form of both quartz veins and stringers accompanies the gold mineralization. Sulphide mineralization, generally less than 5% but up to 30% in the Bell Creek zone, is common. A distinctive type of alteration, referred to as "grey zones", is diagnostic of gold mineralization at the Owl Creek, Hoyle Pond and, to a lesser extent, Bell Creek mines. Amorphous carbon accompanied by enrichments of silica, calcium, potassium, iron, arsenic and gold form sharply bounded to diffuse alteration zones which are the primary exploration targets in southern Hoyle Township (Downes et al. 1984). Although this area has been heavily explored, there remains a potential for more gold mineralization to be discovered, especially in the southwestern portion of the township.

Copper and zinc mineralization hosted at the contact of ultramafic and felsic units was discovered in central Gowan Township by Alamo Petroleum Limited in 1975 (Middleton 1975). Follow-up exploration has been limited by the tightly held patented-land situation, extensive overburden and the nature of the mineralization which is disseminated and, therefore, not easily detected by standard electromagnetic surveys. The bimodal ultramafic and felsic intrusive-volcanic suite is similar to that at the Kidd Creek base metal deposit and is, therefore, a good exploration target. Further work is warranted throughout Gowan Township.

ACKNOWLEDGMENTS

A project of this nature, in an area where outcrop is scarce, is dependent upon co-operation and the mutual exchange of information between government and industry personnel. The author received excellent co-operation from R.J. Labine and L. Burns of Falconbridge Gold Limited, D. Duff of Falconbridge Exploration Limited, R. Roussain and E. Kent of Canamax Resources Incorporated, and B. Cook and P.M. Smith of Cominco Limited. The staff of the Resident Geologist's office in Timmins were most helpful and co-operative. C. Hamblein and M. Leroux, of the Timmins Drill Core Library were especially helpful.

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15. Project Unit 88–33. Structural and Stratigraphic Studies in the Kirkland Lake-Larder Lake Area

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INTRODUCTION

The southwestern Abitibi greenstone belt can be viewed as a collage of distinct supracrustal assemblages (e.g. Jackson and Fyon, in press). Assemblage is an informal term used to refer to a regionally mappable collection of units defined by lithic, structural, geochemical, geochronological and geophysical parameters. Contained units within an assemblage need not obey the "Law of Superposition" but they generally display recognizable primary features. Assemblages are commonly fault bounded.

Characterizing the assemblages and deciphering their stratigraphic and structural relationships, then, is important to the understanding of the geological history of the greenstone belt and its contained mineral deposits. Mapping during the summer of 1991 in the Kirkland Lake-Larder Lake area (mainly in McVittie, McGarry, Gauthier, and Lebel townships; *see* Figure 1) included portions of the following assemblages: 1) the belt of metasedimentary, alkalic metavolcanic, and porphyritic intrusive rocks that extends from Kirkland Lake to the Ontario-Quebec border and is commonly referred to as the Timiskaming assemblage; 2) felsic metavolcanic rocks of the Gauthier assemblage; 3) mafic metavolcanic rocks of the Kinojevis assemblage; and 4) intermediate metavolcanic rocks of the Blake River assemblage. This report summarizes: 1) revisions made to the distribution of metavolcanic rocks and mafic intrusive rocks; 2) observations made on some units of the metasedimentary Timiskaming and Hearst assemblages; and 3) some aspects of the structural geology.

For an extensive reference list for the area, current to approximately the end of 1990, the reader is referred to Jackson and Fyon (in press).

REVISIONS TO DISTRIBUTION OF MAFIC METAVOLCANIC AND INTRUSIVE ROCKS

Kinojevis and Blake River Assemblages

The main changes to the mapped distribution of metavolcanic rocks relative to previous mapping were made in northern McVittie and McGarry townships (*see* Figure 2). The revisions include: 1) the delineation of dark grey (Fe-rich ?) and green

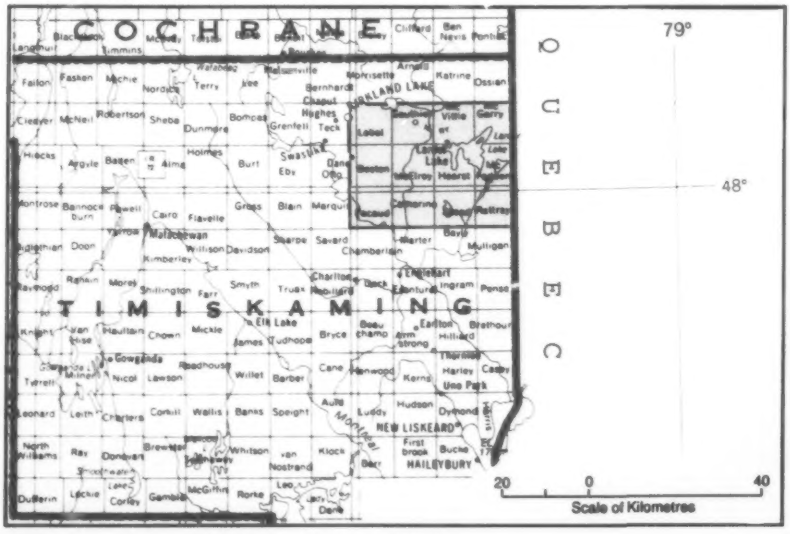

Figure 1. Location map of study area. Scale 1:1 584 000.

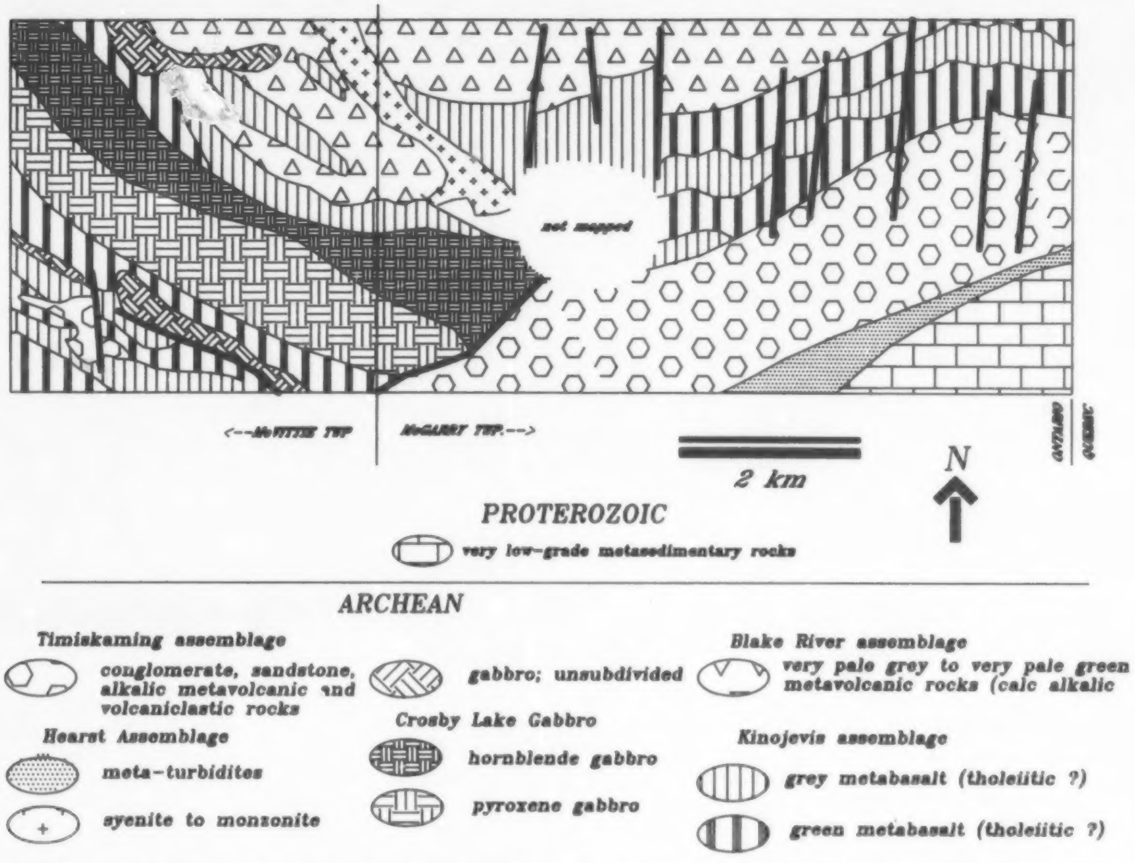
not mapped
<--McVITTIE TWP
McGARRY TWP.-->
ONTARIO
QUEBEC
2 km
N
PROTEROZOIC
very low-grade metasedimentary rocks
ARCHEAN
Timiskaming assemblage
conglomerate, sandstone, alkalic metavolcanic and volcaniclastic rocks
Hearst Assemblage
meta-turbidites
syenite to monzonite
gabbro; unsubdivided
Crosby Lake Gabbro
hornblende gabbro
pyroxene gabbro
Blake River assemblage
very pale grey to very pale green metavolcanic rocks (calc alkalic
Kinojevis assemblage
grey metabasalt (tholeiitic ?)
green metabasalt (tholeiitic ?)

Figure 2. Geological sketch map of northern McGarry Township and northeastern McVittie Township (modified after Thompson 1943).

to pale green (Mg-rich?) tholeiitic metabasalt; and 2) the delineation of very pale grey to very pale green metavolcanic rocks that include pillow basalt, pillow breccia, and intermediate fragmental metavolcanic rocks of possible calc-alkalic origin. Following Jensen (1985a, 1985b) the darker-coloured units (tholeiitic ?) are assigned to the Kinojevis assemblage and the very pale-coloured units (calc-alkalic ?) are assigned to the Blake River assemblage. Samples for geochemistry have been collected from some of the units to help discern their chemical affinity. The extension of units beyond areas of field observation was accomplished through the use of 1:50 000 scale aeromagnetic maps. While this technique is generally successful, in regions where units have been extrapolated, the map should only be regarded as qualitatively correct. The revised map (e.g., Figure 2) shows that units of very light grey to very light green (calc-alkalic ?) metavolcanic rocks are **interlayered** with dark grey to pale green (tholeiitic ?) metavolcanic rocks. Poor outcrop exposure did not permit identification of the nature of the interlayering (e.g., fault or stratigraphic).

Crosby Lake Gabbro

The Crosby Lake Gabbro is a large intrusion located near the boundary of the Kinojevis and Blake River assemblages (*see* Figure 2). Measurement of hornblende-rich pegmatitic layers and other compositional boundaries suggests that the body dips moderately (~40°) to the northeast. The eastern (top) part of the intrusion consists of very coarse-grained hornblende quartz-gabbro to hornblende gabbro. To the west (bottom), the intrusion consists of medium- to coarse-grained pyroxene gabbro to leucocratic pyroxene gabbro. The lowermost portion of the intrusion appears to contain two mafic phases, one of which appears to be clinopyroxene, and the other of which is rusty-orange weathering (possibly altered orthopyroxene ?). Petrographic work will help to clarify the mineralogical zonation of the intrusion.

Comment on Mineral Potential

The Blake River assemblage in Quebec is well known for its large number of contained, volcanic-associated, base-metal sulphide deposits (e.g., Gibson and Watkinson 1990), whereas the Ontario portion of the Blake River assemblage is conspicuously lacking such deposits. Various authors (e.g., Lesher et al. 1986; Ujike and Goodwin 1987) have noted the distinct rare-earth element, and other, geochemical signatures of "tholeiitic" rhyolites of the Noranda camp. Such rhyolites, as so far reported, appear to be lacking from the Blake River assemblage in Ontario (e.g., data of Smith 1980; Capdivella et al. 1982; Lesher et al. 1986; Fowler and Jensen 1989). In Quebec, however, the Blake River assemblage and the Noranda mining camp include metavolcanic rocks of tholeiitic affinity, while in Ontario such rocks have been separated and assigned to the Kinojevis assemblage.

In this context, it is perhaps worth examining, in more detail than this study could afford, the relationships of the Kinojevis and Blake River assemblages in Ontario. Significantly, on Beaverhouse Lake (*see* McVittie Township map of Thomson 1943 for location), there is a large zone of well-developed chlorite veining and epidote alteration—alteration features often spatially associated with base metal deposits. Furthermore, the past-producing Upper Beaver gold mine is associated with vein-type copper-sulphide mineralization.

Comment on Building Stone Potential

The hornblende-gabbro portion of the Crosby Lake Gabbro is locally very massive, contains few fractures, and little disseminated sulphide mineralization. The gabbro could make an attractive dark building stone.

TIMISKAMING AND HEARST ASSEMBLAGES

Comment on Nomenclature

Much discussion has focussed on the relationship of metasedimentary rocks that belong to either the alluvial-fluvial facies association or the turbidite facies association in the Kirkland Lake-Larder Lake area (Thomson 1946; Hewitt 1963; Hyde 1980; Jensen 1985b; Hamilton 1986; Jackson et al. 1990; Corfu et al. 1991). In general, the megascopic characteristics of the two associations are distinct, although the relationship between the two associations is not yet clear (Hyde 1980; Hamilton 1986). For this reason it is appropriate to distinguish the two associations (e.g., Hyde 1980). Following Jackson et al. (1990), **Timiskaming assemblage** is used for the alluvial-fluvial facies association that is commonly associated with alkalic metavolcanic rocks, and **Hearst assemblage** is used for the turbidite facies association which is not associated with alkalic metavolcanic rocks.

Distribution of Hearst Assemblage

The three following metasedimentary units, in addition to those units delineated by Jackson et al. (1990), are included in the Hearst assemblage: 1) The turbidites north of the Larder Lake-Cadillac shear zone that are north and east of Virginiatown are classical well-bedded sandstones and/or mudstones that commonly preserve all members of the Bouma Sequence (e.g. Walker 1986). 2) The turbidites that extend through central Gauthier Township (e.g. "Dobie Basin" of Toogood and Hodgson 1985) are assigned to Hearst assemblage. These turbidites are generally highly deformed with layer- to near layer-parallel foliations and shears. 3) The thin slice of highly deformed turbidites within the main belt of the Timiskaming assemblage that extends roughly from Crystal Lake to Gull Lake (*see* Lebel Township, map of Maclean 1944) may be a "faulted in" portion of the Hearst assemblage. Thin units of turbidite-facies rocks may occur near the northern boundary of the Timiskaming assemblage in Teck Township (Thomson 1948) but these rocks were not examined in this study.

Timiskaming Assemblage Boundary Relationships

The southern boundary of the main belt of the Timiskaming assemblage is marked by the Larder Lake-Cadillac shear zone. The northern boundary of the main belt is commonly sheared (e.g., Hamilton 1986), but unconformities and depositional contacts between the Timiskaming and metavolcanic rocks to the north are well-documented (Thomson 1946; Jackson 1988).

South of the Larder Lake-Cadillac shear zone, on the peninsula of Larder Lake that separates the Southwest Arm from the main body of the lake to the east, there is a matrix-supported conglomerate that contains large boulders of quartz-feldspar porphyry that are identical to a porphyry body located immediately to the north. This conglomerate is overlain by interbedded siltstone-argillite and trough-crossbedded sandstone units—units that are commonly found within the main belt of the Timiskaming assemblage. The conglomerate, then, appears to mark an unconformity between the porphyry and an outlier of Timiskaming assemblage. These observations agree well with the geochronological results of Corfu et al. (1991) and the assignment by Hyde (1980) of these rocks to an alluvial-fluvial facies association.

The boundaries between units of the Timiskaming assemblage and those of the Hearst assemblage appear to be mainly shear zones (e.g., township maps of Thomson 1943 and Thomson and Griffis 1943; Hamilton 1986). It should be pointed out, however, that some very similar rocks occur in each assemblage. For example, both the Hearst assemblage and Timiskaming assemblage include matrix-supported conglomerates and pebbly sandstones (*see* Figure 3; *see also* Jackson et al. 1990).

Regional Patterns of Rock Distribution Within the Timiskaming Assemblage

Examination of existing township maps combined with regional and detailed mapping reveals a general threefold division of the Timiskaming assemblage. The divisions are largely based on associated alkalic metavolcanic rocks.

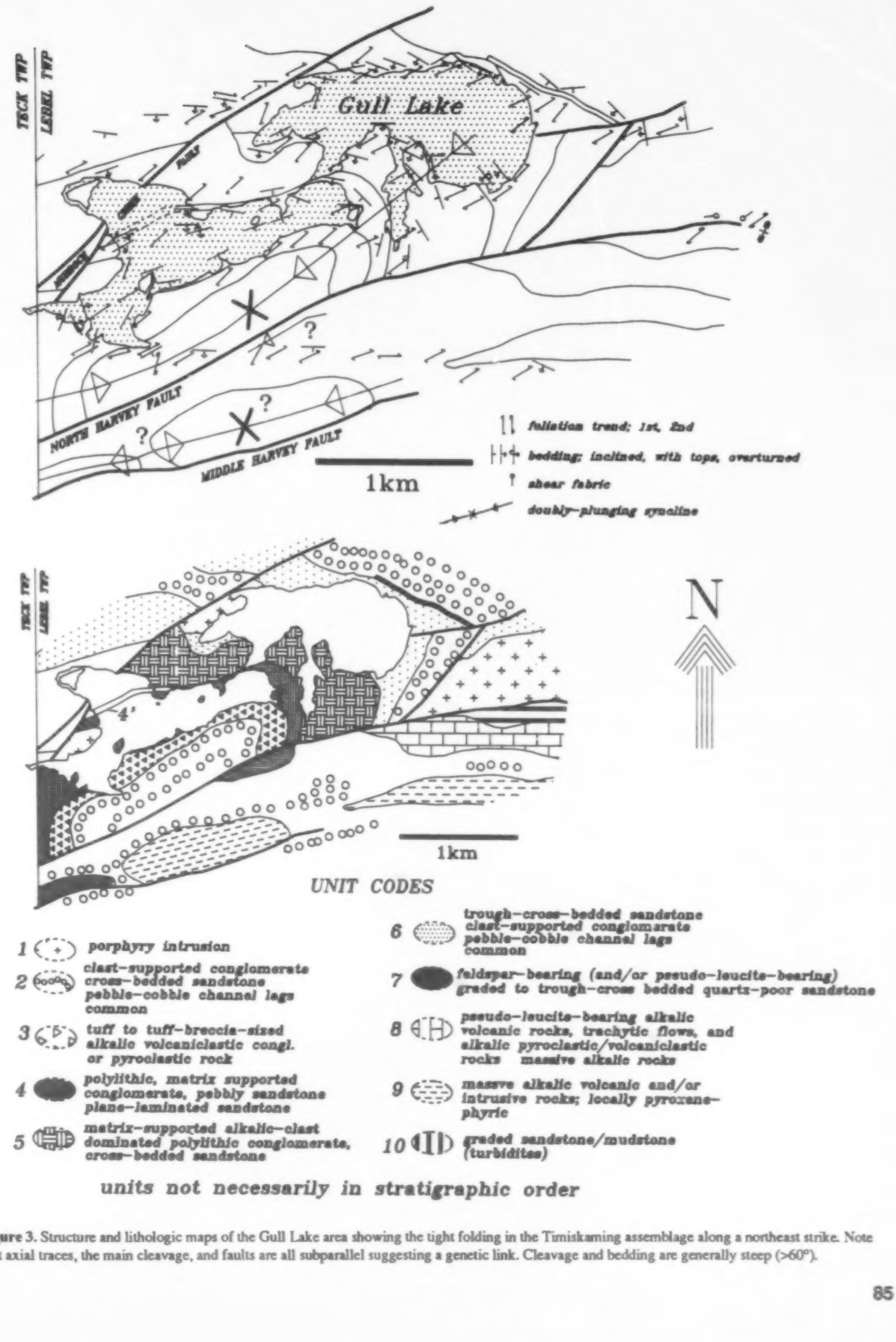
TECK TWP
LEBEL TWP
Gull Lake
NORTH HARVEY FAULT
MIDDLE HARVEY FAULT
?
1km
foliation trend; 1st, 2nd
bedding; inclined, with tops, overturned
shear fabric
doubly-plunging syncline
TECK TWP
LEBEL TWP
4'
1km
N
UNIT CODES
1 porphyry intrusion
2 clast-supported conglomerate cross-bedded sandstone pebble-cobble channel lags common
3 tuff to tuff-breccia-sized alkalic volcaniclastic congl. or pyroclastic rock
4 polylithic, matrix supported conglomerate, pebbly sandstone plane-laminated sandstone
5 matrix-supported alkalic-clast dominated polylithic conglomerate, cross-bedded sandstone
6 trough-cross-bedded sandstone clast-supported conglomerate pebble-cobble channel lags common
7 feldspar-bearing (and/or pseudo-leucite-bearing) graded to trough-cross bedded quartz-poor sandstone
8 pseudo-leucite-bearing alkalic volcanic rocks, trachytic flows, and alkalic pyroclastic/volcaniclastic rocks massive alkalic rocks
9 massve alkalic volcanic and/or intrusive rocks; locally pyroxene-phyric
10 graded sandstone/mudstone (turbidites)
units not necessarily in stratigraphic order

Figure 3. Structure and lithologic maps of the Gull Lake area showing the tight folding in the Timiskaming assemblage along a northeast strike. Note that axial traces, the main cleavage, and faults are all subparallel suggesting a genetic link. Cleavage and bedding are generally steep (>60°).

"Division 1" to the east and "division 2" to the west are separated from one another by a thick, highly deformed belt of turbidite deposits that extends through central Gauthier Township. The Murdoch Creek Fault and North Harvey Fault (*see* maps of Maclean 1944 and Thomson 1948) mark the approximate boundary between "division 2" and "division 3".

"Division 1"

In McGarry and McVittie townships and eastern Gauthier Township, alkalic metavolcanic rocks include feldspar- (± pyroxene) trachytic flows, massive-textured alkalic metavolcanic rocks, and volcaniclastic matrix-supported conglomerates and/or pyroclastic tuff-breccias. Pseudo-leucite-bearing flows have not been reported. The metasedimentary rocks, although not examined in detail in these townships, consist largely of clast-supported, pebble to boulder conglomerates and trough cross-bedded sandstones with pebble to cobble channel lags being common.

"Division 2"

In Lebel Township and western Gauthier Township, the alkalic metavolcanic rocks include pseudo-leucite-bearing flows ("green -and/or red-spotted trachytes"—e.g., Maclean 1944), feldspar- (± pyroxene) trachytic flows, massive fine- to medium-grained alkalic rocks, matrix-supported alkalic volcaniclastic-dominated conglomerates and/or pyroclastic tuff-breccias, and tuffs (*see* Figure 4). In addition to the classical clast-supported conglomerates and trough-cross bedded sandstones with channel lag deposits, metasedimentary rocks in this township include: matrix-supported, heterolithic conglomerates; pebbly sandstones; plane-laminated sandstones; interbedded siltstone and argillite; and either an unusual sandstone or a pyroclastic rock (surge deposit? e.g., Hyde 1978; Goodfish Member, Teck Township) with wavy to planar bedforms and cross-beds, and rounded, isolated, cobble- to boulder-sized, matrix-supported clasts (*see* location 4', Figure 3). The later sediments appear to be debris flow related deposits and are similar, but of lesser extent, to some of the Hearst assemblage turbidite facies rocks (Jackson et al. 1990). Such deposits form an integral part of modern and ancient alluvial fan to fluvial braidplain deposits (e.g., Rust and Koster 1986). An alluvial-fluvial setting is the favoured environment of deposition of the Timiskaming assemblage (e.g., Hyde 1980).

"Division 3"

In Teck Township (west of Lebel Township; not examined for this study) the Timiskaming assemblage appears to consist largely of clast-supported conglomerates, trough-cross-bedded sandstones (commonly with channel lag deposits), and minor siltstone-argillite and turbidite deposits. The "tufaceous conglomerate" and "tuff and agglomerate" units of Thomson (1948) may be comparable to the matrix-supported conglom-

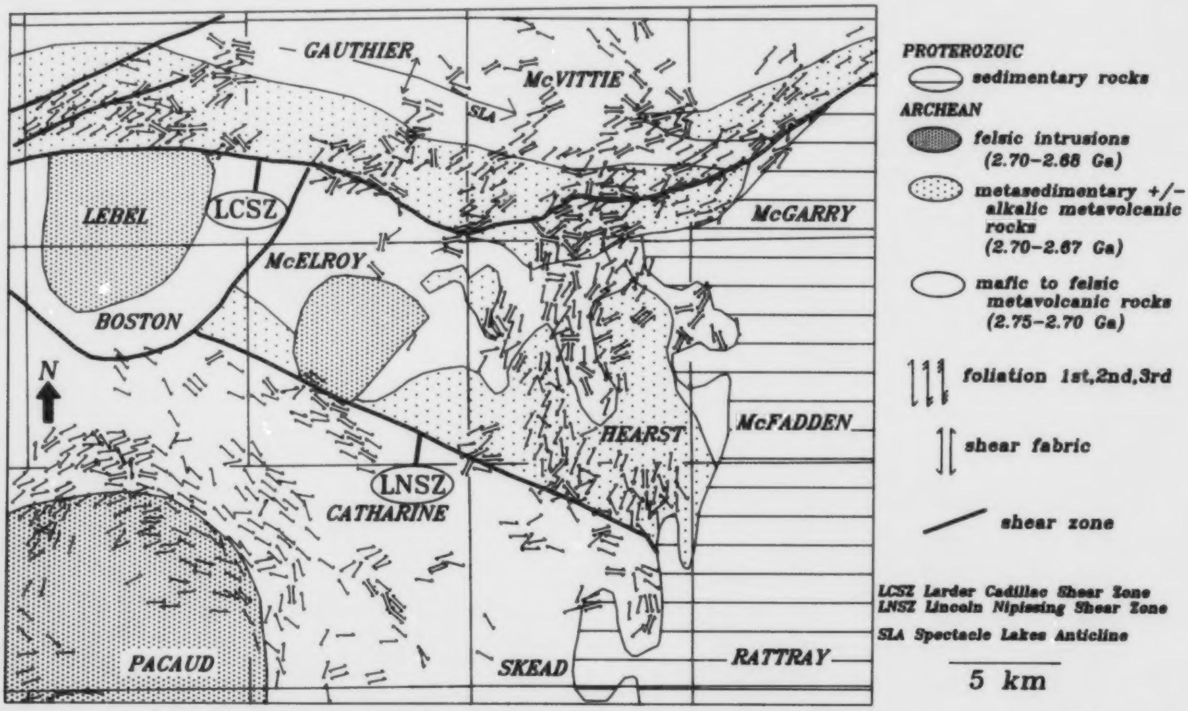
GAUTHIER
McVITTIE
SLA
LEBEL
LCSZ
McGARRY
McELROY
BOSTON
N
HEARST
McFADDEN
LNSZ
CATHARINE
PACAUD
SKEAD
RATTRAY
PROTEROZOIC
sedimentary rocks
ARCHEAN
felsic intrusions (2.70–2.68 Ga)
metasedimentary +/− alkalic metavolcanic rocks (2.70–2.67 Ga)
mafic to felsic metavolcanic rocks (2.75–2.70 Ga)
foliation 1st,2nd,3rd
shear fabric
shear zone
LCSZ Larder Cadillac Shear Zone
LNSZ Lincoln Nipissing Shear Zone
SLA Spectacle Lakes Anticline
5 km

Figure 4. Foliation trends in the greater study area. Note that where cross-cutting relationships are observed, northeast-striking (+/- 20°) foliations are later than other foliation orientations. Note that northeast-striking cleavages overprint the Larder Lake-Cadillac shear zone.

erates and/or tuff-breccia pyroclastic rocks noted above in "division 2" of the Timiskaming assemblage. Little alkalic metavolcanic rock is reported from this division, although there are numerous alkalic intrusions (i.e., porhyritic syenite intrusions).

STRUCTURAL GEOLOGY

Many aspects of the structural relationships in the Kirkland Lake-Larder Lake area have been addressed by Toogood and Hodgson (1985, 1986), Hamilton (1986), Cruden (1990), Hodgson et al. (1990), Jackson et al. (1990), Smith et al. (1990), Jackson and Fyon (in press). In general these studies demonstrate that the regional structural history, apart from batholith emplacement (e.i., Jackson and Harrap 1989), can be subdivided into four main stages: D_1) cleavage-absent folds that predate the Timiskaming assemblage; D_2) post-Timiskaming northwest (± ~20°) oriented folds, faults and foliations; D_3) northeast (± ~20°) oriented folds, faults, and foliations; and D_4) late north (± ~20°) oriented faults, open folds, and cleavage.

Note that D_1, D_2 and D_3 structures may all be part of a regionally continuous deformation history. They are separated here because of their generally consistent overprinting relationships. This summary will address principally the effect of D_2 on rocks of the study area, however, a brief overview of the D_2- and D_4-related structures is also given.

D_2 Structures

D_2 includes those structures and fabrics that post-date the Timiskaming assemblage but predate northeast-oriented structures. For example the Spectacle Lakes anticline (SLA on Figure 4; *see also* Thomson and Griffis 1943) has Timiskaming assemblage rocks on both its north and south limbs (Jackson 1988) and its axial trace is transected by later northeast-trending cleavage and foliation (*see* Figure 4). The anticline is outlined by facing reversals in mafic metavolcanic rocks of the Kinojevis assemblage and is cored by felsic volcaniclastic rocks assigned to the Gauthier assemblage. These felsic rocks possess a well-developed foliation that is locally intense and referred to as a "shear fabric". The foliations and "shear fabrics" are parallel to the axial trace of the anticline.

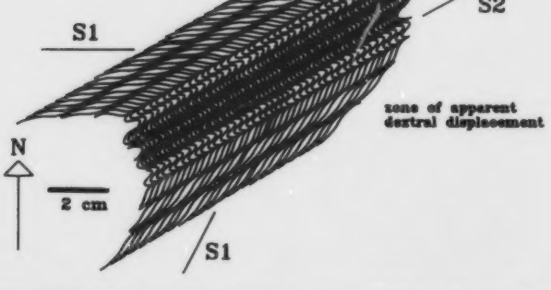

Figure 5. Slightly idealized observed mesoscopic fabric relationships between D_3 cleavage (S_3) and D_2 foliation (S_2). Note on both limbs of the fold, the angular relationship between S_2 and S_3 is different. The crenulation cleavage (S_3) yields apparent sinistral "c-s" fabrics on the northern limb of the fold and apparent dextral "c-s" fabrics on the southern limb.

Within the Timiskaming assemblage, strata-parallel to subparallel shears and foliations are locally present. D_2 foliation is commonly accompanied by a carbonate and/or chlorite-sericite banding. D_2 foliations are commonly overprinted by northeast-striking cleavage.

The well-developed shear fabric associated with the Larder Lake-Cadillac shear zone is also overprinted by northeast-striking cleavage (for a description of the shear zone-related fabrics, see Hamilton 1986; Wilkinson 1991; Peshko 1991). The shear zone, however, appears to transect the eastern end of the D_2 Spectacle Lakes anticline (Hamilton 1986). Consequently the Larder Lake-Cadillac shear zone may developed from late D_2 to early D_3.

D_3 Fabric and Structures

D_3 Fabric

The main D_3 fabric elements are spaced crenulation cleavages, crenulation lineations, minor folds, and locally a micaceous foliation. Differentiation along D_3 is most commonly manifest by relative mica enrichment along the cleavage planes. Understanding distribution of D_3 cleavage and the influence of D_3 cleavage on earlier fabrics, especially those related to the Larder Lake-Cadillac shear zone, is critical to the interpretation of the earlier structures. It can be seen in Figure 4 that northeast-striking cleavage is regionally developed and not confined to the immediate proximity of the Larder Lake-Cadillac shear zone. In Lebel Township, there is no significant regional rotation of D_3 cleavage into the shear zone, and as noted above, D_3 cleavage overprints shear-related fabrics. The D_3 cleavage, then, may represent a strain largely unrelated to the development of the Larder Lake-Cadillac shear zone. Furthermore, it is noted that Z-shaped folds and asymmetric clasts reported from the Larder Lake-Cadillac shear zone (Hamilton 1986; Peshko 1991), although possibly indicative of a minor late dextral component of slip along the shear zone, may also be a result of re-orientation of shear fabric and clasts into the D_3 flattening plane (e.i., Hamilton 1986).

Although both dextral and sinistral horizontal components of displacement have been reported from the Larder Lake-Cadillac shear zone, the prominent stretching lineation plunges steeply to obliquely down-dip (e.i., Hamilton 1986; Jackson et al. 1990; Wilkinson 1991) suggesting dominantly dip-slip to slightly oblique-slip displacement. The D_3 cleavage, in addition to folding previously stretched and flattened clasts, and producing z-shaped folds of the shear fabric, has the added potential of producing conflicting **apparent** "c-s" kinematic indicators (*see* Figure 5). This may account for some of the conflicting kinematic interpretations of the Larder Lake-Cadillac shear zone in Ontario.

D_3 Map-Scale Structures

Northeast-striking (± 20°) D_3 faults, folds, and cleavage are generally oriented at a moderate to high angle to the regional trends of units and earlier structures. At a small scale (1:50 000 to 1:250 000) these structures do not significantly offset units laterally. This conclusion is supported by: 1) detailed mapping of D_3 shear zones and zones of well developed D_3 cleavage where units can be traced across the shear zones and zones of cleavage development (*see* Figure 4); 2) the detailed relationships of D_3 cleavage to earlier fabrics (*see* Figure 5); and 3) the piercing point analysis of Thomson et al. (1948) on the Kirkland Lake Main Break (interpreted as a D_3 shear zone) which indicates that it is a dip-slip, south-side up reverse fault. The D_3 shear zones and cleavages, then, are interpreted as predominantly pure shear to dip-slip shear zones and/or zones of well-developed flattening fabrics (e.i., Hodgson and Hamilton 1989).

The Gull Lake area provides an excellent example of the effect of D_3 on the Timiskaming assemblage (*see* Figure 3). There, the D_3 northeast-striking (± 20°) cleavage is axial planar to a doubly-plunging fold of the Timiskaming assemblage. Such folds are well developed in Lebel and Teck Townships (*see* maps of Maclean 1944 and Thomson 1948). The doubly plunging syncline south of Gull Lake is asymmetric along its axial trace with steeply-dipping beds at the northern closure and shallowly dipping beds at the southern closure. An analogy would be a northeast oriented canoe with its northeast end lower than its southwest end. The preserved north limb of the syncline is steeply to moderately dipping and the southern limb is truncated by the North Harvey Fault. South of the North Harvey Fault, a tight anticline may exist. The syncline south of Gull Lake, then, is bounded to the north and south by the Murdoch Creek Fault and the North Harvey Fault, respectively. These faults are subparallel to the main cleavage direction and the fold axial trace. These faults are considered to be an integral part of the same D_3 deformation that produced the folds. It is speculation at present to infer a displacement sense for these structures, but they may be reverse faults with a south over north polarity. Further work needs to be done to determine if the doubly-plunging nature of the folds in Lebel and Teck Townships is the result of fold interference, or if they formed during one phase of folding. It is also important to note that in Lebel Township the northeast-striking cleavage associated with the Gull Lake structures locally overprints earlier, near strata-parallel foliations and shears.

Significance of D_3 Structures to Gold Mineralization

Most of the large gold deposits in the Kirkland Lake area are spatially associated with the Timiskaming assemblage and the Larder Lake-Cadillac shear zone (e.i., Colvine et al. 1988). Within this general framework, most of the large gold deposits are, however, associated with northeast- to east-northeast-striking (± 20°) shear zones (e.i., the Kirkland Lake main break and associated mines, such as the Macassa Mine; the Northeast Arm shear zone of Hamilton (1986) and the Kerr Addison mine). Many smaller gold deposits in Lebel Township are also associated with veins and shears oriented northeast to east-northeast. The above structures may be an integral expression of the D_3 deformation in the region.

D_4 Structures

The youngest regionally developed structures in the map area, excluding some northwest-striking faults related to the Timiskaming Graben (Kumarapeli and Saull 1966), are north-striking (± 20°) faults and open folds (*see* Figure 2). The faults generally display left-handed offset (*see* Figure 2).

SUMMARY

Some of the main results of 1991 field work are:

1. Revisions to the distribution of metavolcanic and mafic intrusive rocks have been made in northern McVittie and McGarry Townships.
2. The Kinojevis and Blake River assemblages are interlayered, although the cause of the interlayering is not known.
3. A chlorite-epidote alteration system is present on western Beaverhouse Lake and may represent a target area for base-metal exploration.
4. The Timiskaming assemblage can, at a regional scale, be subdivided into three main divisions. The divisions are separated by faults and/or regions of structural complexity.
5. The Timiskaming assemblage in Lebel Township contains a significant amount of debris flow-related sedimentary rocks.
6. The Timiskaming assemblage is tightly folded and reverse(?)-faulted along a northeast strike in Lebel Township and parts of Teck Township.
7. D_3 (northeast ± 20°) foliations and shear zones are spatially associated with many gold zones within the Timiskaming assemblage. This deformation appears to represent a relatively late north-northwest-directed flattening of the greenstone belt. D_3 crenulation cleavages overprint carbonate-feldspathic and sericite-chlorite banding related to earlier structures.

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16. Project Unit 91–07. Geology of Argyle and Baden Townships, District of Timiskaming

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INTRODUCTION

Geological mapping at a scale of 1:20 000 was initiated to provide a modern geological database for part of the Matachewan area following the recent discovery of base metal sulphides in Robertson Township. The map area (Figure 1) comprises Argyle and Baden townships, includes the western portion of Matachewan Indian Reserve 72 and covers an area of 200 km^2.

Both townships have been mapped in the past, Argyle Township by H.C. Rickaby (1932), and Baden Township by W.S. Dyer (1936). H.L. Lovell (1963) mapped Baden Township at a scale of 1:15 840. Geophysical series maps (ODM 1975a, 1975b) provide the most recent airborne magnetic and electromagnetic coverage of the area.

The centre of the map area is located approximately 17 km northwest of the community of Matachewan in northeastern Ontario. Highway 566 and Matachewan and Mistinikon lakes provide access to the area.

MINERAL EXPLORATION

The earliest gold discovery in the Matachewan gold camp was made in 1916 on what was to become the Young-Davidson Mine Limited and the Matachewan Consolidated Limited properties in Powell Township (Lovell 1967). During their production years of 1934 to 1957, both mines produced nearly 1 million ounces of gold. The two properties were recently re-evaluated by an extensive diamond drilling program.

In 1930, rich gold-bearing veins were found at what was to become the site of the Ashley Mine in northwestern Bannockburn Township. This mine produced 50 099 ounces of gold between 1931 and 1937 (Assessment Files Research Office, Ontario Geological Survey, Toronto). The discovery of the Ashley gold deposit sparked intense prospecting activity in both Argyle and Baden townships resulting in the discovery of several gold showings. In subsequent years, staking and exploration were concentrated in the vicinity of the early discoveries. More recently, many of the showings and the ground nearby were investigated by overburden stripping, geological mapping, and geophysical prospecting (Assessment Files Research Office, Ontario Geological Survey, Toronto and assessment files, Resident Geologist's office, Kirkland Lake).

The area has also been intermittently explored for base metal mineralization. Recent prospecting activities were, to a large degree, encouraged by incentive programmes put in place by the Ontario Government (Assessment Files

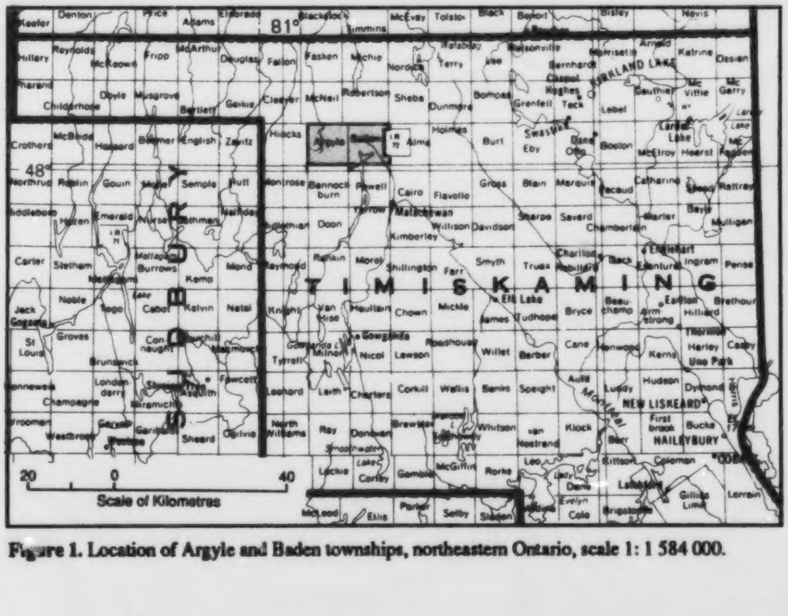

Figure 1. Location of Argyle and Baden townships, northeastern Ontario, scale 1: 1 584 000.

Research Office, Ontario Geological Survey, Toronto and assessment files, Resident Geologist's office, Kirkland Lake).

GENERAL GEOLOGY

The two townships are underlain by rocks of mainly Archean age which consist largely of metamorphosed volcanic rocks. These metavolcanic rocks are intruded in several places by granitic rocks and, in a few places, by mafic, ultramafic and alkalic rocks. Numerous north-trending diabase dikes have been emplaced in the Early Proterozoic. The youngest Precambrian rocks in the area belong to the Huronian Supergroup and occur in an outlier in south-central Argyle Township.

Glacial drift cover is thin, except for some thicker local deposits of sand and gravel associated with eskers. The distribution of the major rock units is shown in Figure 2.

Archean

METAVOLCANIC ROCKS

Two compositionally distinct groups of metavolcanic rocks have been recognized within the map area: 1) a lower mafic, tholeiitic sequence, and 2) an extensive sequence of tephra deposits and flows of intermediate composition. These two groups are part of units of regional extent which form major subdivisions within the lithostratigraphy of the Abitibi Subprovince (MERQ-OGS 1983).

The mafic tholeiitic volcanic rocks of the map area are composed of massive and pillowed, aphyric flows which are locally amygdaloidal. A thin, variolitic, mafic flow represents a stratigraphic marker horizon in southwestern Argyle and southern Baden townships. All the mafic flows are part of the sequence which has been referred to as the Kinojevis Group in the Kirkland Lake area (MERQ-OGS 1983).

The rocks overlying the mafic metavolcanics form the bulk of the metavolcanic sequence within the map area. They are composed of extensive units of tuff, lapilli tuff and tuff

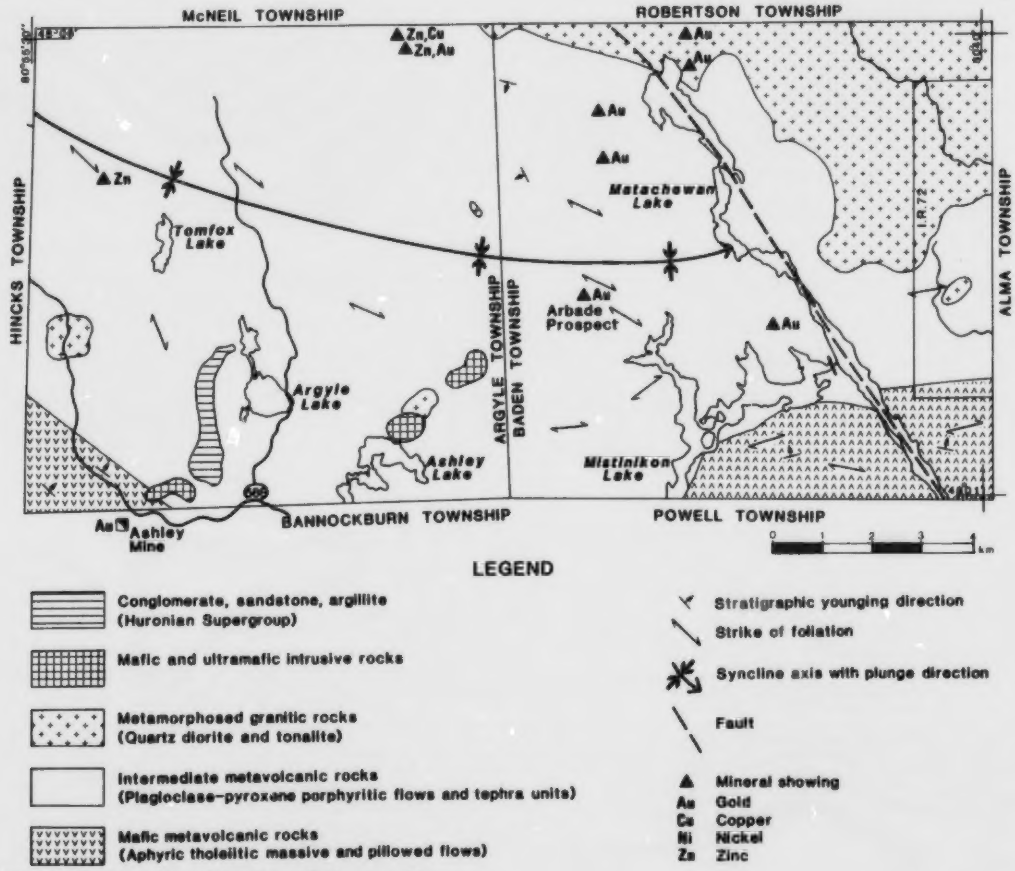
McNEIL TOWNSHIP
ROBERTSON TOWNSHIP
HINCKS TOWNSHIP
ALMA TOWNSHIP
ARGYLE TOWNSHIP
BADEN TOWNSHIP
BANNOCKBURN TOWNSHIP
POWELL TOWNSHIP
I.R.72
Zn,Cu
Zn,Au
Zn
Au
Tomfox Lake
Matachewan Lake
Arbade Prospect
Argyle Lake
Ashley Lake
Mistinikon Lake
Au Ashley Mine
0 1 2 3 4 km
LEGEND
Conglomerate, sandstone, argillite (Huronian Supergroup)
Mafic and ultramafic intrusive rocks
Metamorphosed granitic rocks (Quartz diorite and tonalite)
Intermediate metavolcanic rocks (Plagioclase–pyroxene porphyritic flows and tephra units)
Mafic metavolcanic rocks (Aphyric tholeiitic massive and pillowed flows)
Stratigraphic younging direction
Strike of foliation
Syncline axis with plunge direction
Fault
Mineral showing
Au Gold
Cu Copper
Ni Nickel
Zn Zinc

Figure 2. General geology of Argyle and Baden townships.

breccia with a uniform monolithological character. Massive, pillowed, and commonly amygdaloidal flows are associated with the pyroclastic deposits. Both the flows and the pyroclastic rocks are characterized by the widespread presence of plagioclase and pyroxene phenocrysts, which, in places, are very abundant. The lighter colour and the almost invariable presence of phenocrysts distinguish this sequence from the underlying basaltic rocks and suggest that the rocks are andesitic in composition. In the Kirkland Lake and Noranda areas, rocks of similar composition overlying the Kinojevis Group constitute a major sequence referred to as the Blake River Group (MERQ-OGS 1983).

At Mistinikon Lake, a rhythmically layered cherty tuff unit marks the transition from basaltic to andesitic volcanism. Intrusive rocks related to the volcanic rocks are minor within the map area.

METASEDIMENTARY ROCKS

The only Archean sedimentary rocks recognized in the map area are 1) thin units of cherty mudstone with magnetite iron formation occurring in one place in southeastern Baden Township, between flows of the Kinojevis Group and 2) a well-bedded, cherty tuff unit in Baden Township marking the transition between the Kinojevis and Blake River groups.

INTRUSIVE ROCKS

Three small mafic to ultramafic intrusions were identified in southern Argyle Township. They consist of medium- to coarse-grained, massive, mica-bearing pyroxenite or peridotite. These rocks are surrounded by gabbroic and very coarse-grained, granitic phases ranging from diorite to tonalite. This association of rocks appears to form a small intrusive complex. Strong magnetic anomalies are associated with the intrusions (ODM 1975a).

The Archean volcanic assemblage is intruded in northern Baden Township by medium-grained, tonalitic rocks. These rocks appear to be associated with a larger granitic complex to the north (Pyke et al. 1973).

A stock, 1 km across, of hornblende-bearing quartz diorite intrudes the metavolcanic rocks in western Argyle Township. Several outcrops of quartz diorite to tonalite, probably representing dikes, were found in a few places in Argyle Township.

Several dikes of syenite and mafic syenite were found within both volcanic assemblages. Syenite intrusions are known to be associated with several gold deposits in the Matachewan area (Lovell 1967) and may therefore have played a genetic role in gold mineralization in the region.

Proterozoic

Numerous north-trending diabase dikes cross-cut all Archean rocks. They are particularly abundant in eastern Baden Township. These dikes locally carry large apple-green plagioclase phenocrysts and are up to 60 m in thickness. They probably all belong to the Matachewan-Hearst swarm, which has been dated at 2454 Ma (Heaman 1988).

An outlier of subhorizontally dipping sedimentary rocks of the Gowganda Formation of the Cobalt Group (Huronian Supergroup) uncomformably overlies the Archean metavolcanic rocks west of Argyle Lake. These rocks consist of interbedded polymictic conglomerate, arkose, and wacke-mudstone.

METAMORPHISM AND ALTERATION

All Archean supracrustal rocks have been subjected to low greenschist-facies metamorphism. No higher grade metamorphic aureoles were noted in the vicinity of granitic intrusions, possibly suggesting that the granitic rocks and the aureoles around them have also been metamorphosed. Local hydrothermal silicification, carbonatization, sericitization, chloritization and sulphide dissemination have been observed. In the southern part of the map area, silicified and seritized metavolcanic rocks of intermediate composition have previously been described as "bleached" by Lovell (1963, 1967). Some of these rocks also contain fuchsite. These altered rocks commonly have a foliation. Carbonatization has been found associated with numerous shear zones, as well as some syenite and quartz porphyry dikes.

The Proterozoic rocks have been subjected to subgreenschist-facies metamorphism.

STRUCTURAL GEOLOGY

The Archean supracrustal assemblage within the map area has been folded into a large easterly plunging syncline. This is evident from both the regional stratigraphic relationships as well as from younging direction. Bedding appears to have steep to vertical dips throughout the map area. Primary structures such as pillows, clasts, and amygdules appear to be tectonically undeformed in much of the map area. Where deformed, rocks exhibit a steeply to vertically plunging lineation within the foliation plane. Hydrothermal alteration is commonly associated with strongly foliated rocks. Foliations such as a spaced fracture cleavage or schistosity in general appear to be axial planar to the syncline. Deformation zones show evidence of predominantly brittle, rather than ductile deformation. Matachewan Lake defines a prominent topographic lineament and represents a late northwest-striking fault.

ECONOMIC GEOLOGY

Gold is the commodity of principal interest in the map area and is associated with quartz or quartz-carbonate veins and small stockworks within both metavolcanic rocks and granitic rocks. Various intrusive rocks appear to have a close spatial association with gold mineralization. Pink granitic dikes with sparsely distributed quartz eyes are found at the Ashley Mine. Syenite dikes which may be strongly carbonatized are found at the Arbade prospect. Lamprophyre dikes are also found in two carbonatized shear zones near the Ashley Mine and in northern Baden Township, respectively. It is possible that these dikes have a genetic relationship with gold mineralization. Carbonatization, characterized by a strong rusty weathering, is associated with every gold occurrence in the map area. Pyrite is always associated with auriferous quartz veins which also may contain other sulphides in minor quantities.

Base metal mineralization occurs in a few places. Nickel-copper mineralization was reported in a metamorphosed peridotite dike in northeastern Argyle Township. Zinc mineralization occurs in a sheared metavolcanic rock northwest of Tomfox Lake. Significant Cu-Zn mineralization was recently found in metavolcanic rocks in Robertson Township.

RECOMMENDATIONS FOR MINERAL EXPLORATION

Gold occurs mostly in quartz veins or stockworks associated with sheared and hydrothermally altered rocks. Zones of silicification, sericitization, and carbonatization and the presence of sulphides in deformed rocks should be carefully investigated, particularly if such rocks fall on trend with known gold occurrences or shear zones.

Cherty mudstone interbeds within metavolcanic sequences or between two compositionally distinct metavolcanic units should be investigated for their potential of Cu-Zn-Pb type deposits.

ACKNOWLEDGMENTS

Xiangdong Jiang, senior assistant, mapped about one-third the map area. Junior assistants were J.P. Edwards, G.O. Horvath, and L.A. Semenyna. Robert Batisse gave permission to map the western part of Matachewan Reserve No. 72.

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17. Project Unit 91–08. Geology of the Mazinaw Area

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INTRODUCTION

The Mazinaw area (NTS 31C/14N, 31F/3SE) (Figure 1) is located 70 km north-northeast of Napanee, and approximately 230 km northeast of Toronto. The map area covers about 650 km², and is bounded by latitudes 44°52'30"N and 45°05'N and longitudes 77°00'W and 77°20'W. The area lies within parts of Frontenac, and Lennox and Addington counties, and includes parts of Abinger, Anglesea, Barrie, Clarendon, Effingham, and Miller townships. The village of Plevna is located on the east boundary of the map area. Access is provided by highways 41 and 506 and the Buckshot Road. Additional access is provided by cottage roads, powerline right-of-ways, numerous logging roads, and several cut trails. The map area includes Bon Echo Provincial Park, and we are grateful to the Ministry of Natural Resources for providing access to the park during the course of this study.

MINERAL EXPLORATION

Barrie Township has had a long history of gold exploration and minor gold production dating back to the turn of the century (cf. Meen 1944; Barron 1983; Moore and Morton 1986; LeBaron 1991). Barron (1983) and LeBaron (1991) summarize recent exploration activity in the township. Many deposits are located near the Flinton Group-Grenville Supergroup unconformity, although the role this unconformity played in siting mineralization is unclear.

Smith (1958) and Pauk (1987) summarize the exploration history of Barrie and Clarendon townships, respectively. Little exploration activity has been conducted in Abinger, Effingham and Miller townships within the map area. Malzack et al. (1985) provide an inventory of base metal, molybdenum and precious metal deposits in NTS Sheet 31C (Kingston), including the Mazinaw area. Geological Data Inventory Folios (GDIF) are available for Abinger (OGS 1984b), Anglesea (OGS 1984d), Barrie (OGS 1984e), Clarendon (OGS 1984f), Effingham (OGS 1984a), and Miller (OGS 1984c) townships.

GENERAL GEOLOGY

Introduction

The Mazinaw area is underlain by Precambrian rocks of Middle to Late Proterozoic age which form part of the Central Metasedimentary Belt of the Grenville Structural Province. The area straddles the boundary between the

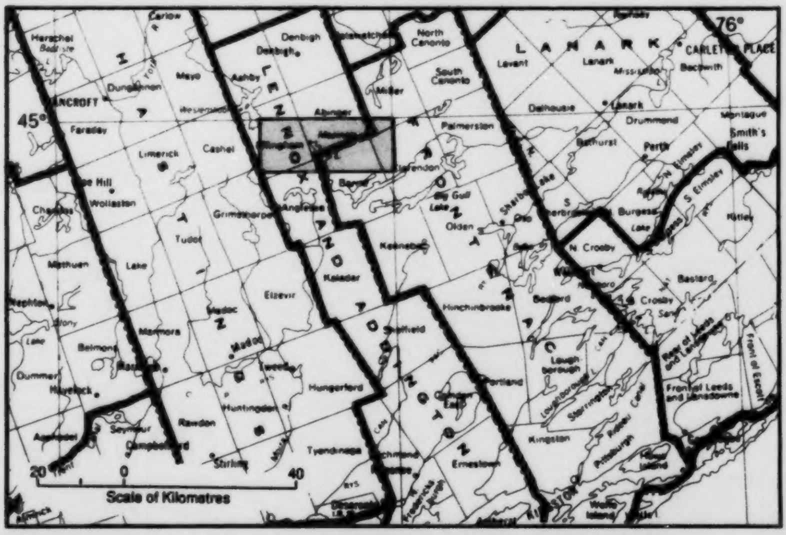
45°
76°
L A N A R K
Denbigh
Ashby
Abinger
Miller
North Canonto
South Canonto
Palmerston
Levant
Lanark
Dalhousie
Drummond
Bathurst
Perth
Montague
Smith's Falls
Beckwith
Limerick
Cashel
Faraday
Mayo
Dungannon
Wollaston
Grimsthorpe
Anglesea
Tudor
Barrie
Big Gull Lake
Olden
Kennebec
N. Crosby
Burgess
Methuen
Lake
Elzevir
Kaladar
Madoc
Marmora
Belmont
Dummer
Havelock
Huntingdon
Rawdon
Hungerford
Sheffield
Hinchinbrooke
Bedford
Crosby
Bastard
Portland
Loughborough
Storrington
Kingston
Ernestown
Tyendinaga
Seymour
Campbellford
Stirling
Front of Leeds and Lansdowne
20
0
40
Scale of Kilometres

Figure 1. Location map of the study area in the Grenville Province, scale 1:1 584 000.

Mazinaw Terrane and the Grimsthorpe domain of the Elzevir Terrane (Easton, in press) (*see* Figure 2). Easton and Ford (1990) termed this boundary the Mooroton shear zone. In the extreme northern part of the area, the Mazinaw Terrane is in fault contact with the Bancroft Terrane (*see* Figure 2). East-striking faults, most likely of Paleozoic age and probably related to the Ottawa-Bonnechere graben system, cut through the western part of the map area (*see* Figure 3). These faults are difficult to trace in the eastern part of the map area, in part because they are subparallel to regional trends of rock units within the Mazinaw Terrane. A set of north-northwest-trending faults of unknown age transect the map area (*see* Figure 3) and are most abundant near Mazinaw Lake and the Mazinaw-Elzevir terrane boundary.

The Grimsthorpe domain of the Elzevir Terrane (Easton, in press; Easton and Ford 1990) consists of, from oldest to youngest: a) a sequence of tholeiitic metabasalts intruded by metagabbro and metaperidotite (Canniff Complex); b) metaconglomerate, metawacke and metapelite (Grimsthorpe Group), with minor intercalated tholeiitic metabasalt flows (Grimsthorpe Group), derived from a dominantly mafic volcanic source region and the Canniff complex; c) metagabbro, with hornblendite pods and anorthositic metagabbros of the Killer Creek Gabbro Suite (Easton and Ford 1990), referred to as Killer-type gabbros of >1270 Ma. These gabbros are characterized by high TiO_2 (>2.5%) and P_2O_5 (>0.6%) contents (Easton and Ford, in prep.); d) metatonalites and minor metagranodiorites of the *ca.* 1270 Ma Elzevir Suite (Easton, in press; Lumbers et al. 1990) including the Canniff, Elzevir and Weslemkoon tonalites and which locally form intrusion breccias of tonalite and Killer-type gabbro; and e) the *ca.* 1090 Ma Skootamatta Syenite.

Rocks of the Grimsthorpe domain are preserved at greenschist facies in the southern and central regions of the domain, reaching amphibolite facies in the north, which includes most of the domain in the map area (Figure 2). Only one major regional metamorphic event appears to have affected the Grimsthorpe domain. Deformation in the domain is localized in shear zones, and most rocks preserve relict primary textures, including igneous layering in the gabbroic rocks and fine bedding features in the metasediments (Easton and Ford 1990).

The Mazinaw Terrane consists of, from oldest to youngest: a) metatonalite and metagranodiorite intrusions of *ca.* 1270 Ma age (Lumbers et al. 1990), including the Northbrook and Cross Lake tonalites and locally intrusion breccias containing Killer-type gabbros, particularly in the map area; b) basalt-andesite-dacite-rhyolite metavolcanics of the Kashwakamak Formation of calc-alkalic affinity (Moore and Morton 1986; Condie and Moore 1977; Harnois and Moore 1988); c) siliciclastic metasedimentary rocks (metawacke, semi-pelites, para-amphibolites), in part derived from metavolcanic rocks; d) calcitic and dolomitic marbles; e) fine- to medium-grained, heterogeneous granitic rocks (Abinger and Norway Lake granites in the map area, Figure 3); and f) the *ca.* 1157 Ma (maximum age of deposition, Kinsman and Parrish 1990) Flinton Group which unconformbly overlies all older rock units. The Mazinaw Terrane has been subjected to at least two regional metamorphic episodes. The first, M_1, reaching upper amphibolite and perhaps granulite facies locally, affected all rocks older than the Flinton Group, and was accompanied by intense deformation (D_1), which formed much of the penetrative fabric currently preserved in the rocks. D_1 was accompanied by thrusting and isoclinal folding, which formed regional fold structures in the area, and is >1160 Ma in age. The second metamorphic event (M_2) affected the Flinton Group, as well as all older rocks, and is <1150 Ma in age. The metamorphic pattern in the map area reflects M_2, with greenschist-facies conditions (chloritoid-staurolite) present southeast of Marble Lake, rising to upper amphibolite (sillimanite) facies along the northern and eastern boundaries of the map area. M_2 was

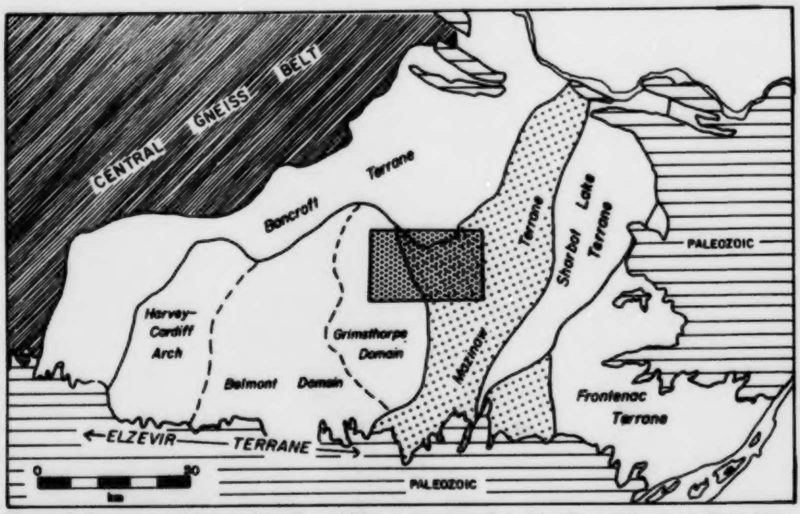

Figure 2. Terrane subdivision of the Central Metasedimentary Belt (after Easton, in press). Shaded box shows position of the map area.

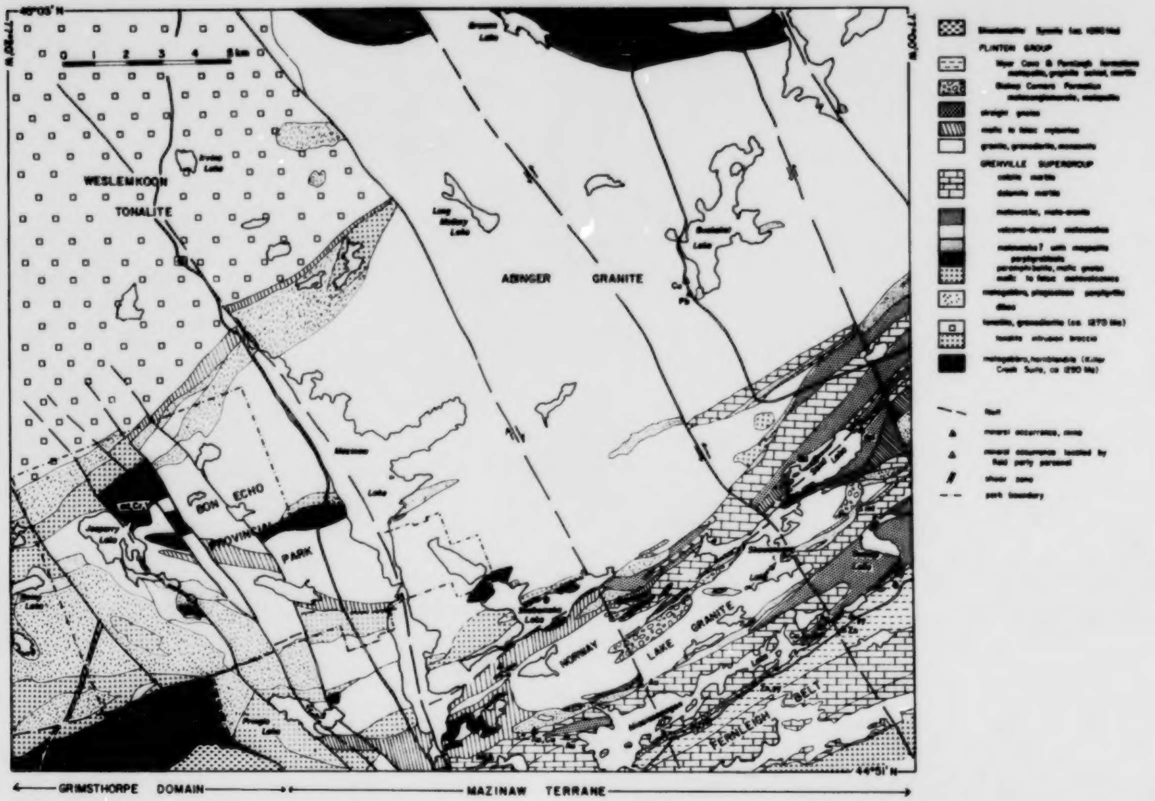

Figure 3. Geologic sketch map showing major rock units, structures and mineral occurrences within the Mazinaw area.

accompanied by only localized deformation (shearing, minor folding, refolding of older structures) and was responsible for the growth of randomly oriented porphyroblasts (hornblende, microcline, staurolite, chloritoid, kyanite, tourmaline) in most rocks units, including metaplutonic rocks.

The Grimsthorpe domain has been well described by Easton and Ford (1990), and no significant changes to our knowledge of this domain were made during the course of mapping the Mazinaw area. Consequently, this report will focus on the geology of the Mazinaw Terrane, which underlies the eastern two-thirds of the map area (Figure 3).

Shear Zones and Pre-M_2 Mylonites

Critical to the understanding of the geology of the map area is the recognition of two pre-M_2 shear zones trending east-northeast across the centre of the map area, along the northern and southern flanks of the Norway Lake granite (Figures 3 and 4). The northern and southern shear zones are termed the Shabomeka and Swamp Lake shear zones, respectively (Figure 3). These shear zones have not been described previously, although Rivers (1976) described recrystallized mylonitic rocks lying along the eastward extension of these zones in the Sand Lake area and north of Ardoch. Rivers (1976) interpreted these rocks as mylonites because the layering in the rocks is much finer (<2 mm) in scale than typically observed in metamorphosed supracrustal rocks in the area, the grain size of calcite in calc-silicate and marble units varied by an order of magnitude between layers (0.2–200 mm) and the lithologies displaying the layering varied along strike. These observations are similar to our own. In addition, in the Shabomeka shear zone, quartzofeldspathic gneiss, locally containing porphyroclasts of plagioclase, are present, indicating that grain-size reduction did occur. These gneisses also contain garnet and magnetite porphyroblasts which probably developed during M_2. Rivers (1976) suggested that the protoliths were either fine grained when mylonitization occurred, or mylonitization was very intense. Both suggestions probably apply. In the Shabomeka (northern) shear zone, pods of metagabbro, predominantly of Killer-type, are common (Figure 3), containing relatively undeformed cores, but becoming progressively mylonitized toward the margins of the pods until the rocks can only be described as finely laminated, mafic gneisses.

Three main lithologic types are present within the shear zones. 1) Finely laminated, pink, buff, or grey weathering, quartzofeldspathic gneisses ("felsites"), locally containing garnet, plagioclase or magnetite porphyroclasts. 2) Finely laminated, green to dark green biotite-hornblende-plagioclase mafic gneisses. The mafic gneisses are commonly intercalated on a 5 to 30 m scale with the quartzofeldspathic gneisses.

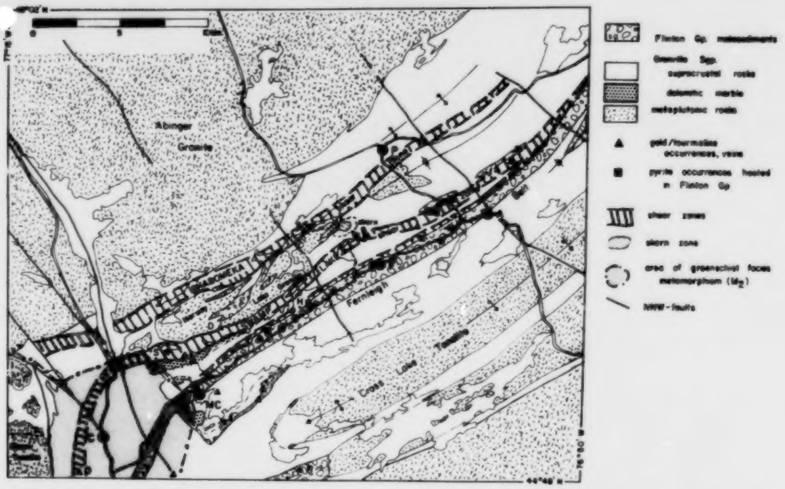
Abinger Granite
Fernleigh
Cross Lake
A
MC
Flinton Gp. metasediments
Grenville Sgp.
supracrustal rocks
dolomitic marble
metaplutonic rocks
gold/tourmaline occurrences, veins
pyrite occurrences hosted in Flinton Gp
shear zones
skarn zone
area of greenschist facies metamorphism (M_2)
NNW-faults

Figure 4. Distribution of gold and sulphide occurrences within the Mazinaw area and environs, as well as major shear zones and the Flinton Group. Abbreviations: A=hamlet of Ardoch; B=Boerth Mine; C=hamlet of Cloyne; F=hamlet of Fernleigh; D=Big Dipper Mine; H=Hardie (Gough) Property; J=James Property; K=Buckhorn property; MC=Myer Cave; O=O'Donnell properties; P=hamlet of Plevna; R=Pay Rock property; S=Star Mine.

3) Foliated, grey weathering, hornblende-biotite-plagioclase gneisses which contain randomly oriented garnet ± magnetite ± hornblende porphyroblasts. These gneisses are sugary-textured, and resemble metawackes, although they shown no obvious bedding features, and form thick, homogeneous units. They may represent a mylonitized dioritic protolith, or a mylonitized sequence of compositionally homogeneous volcanic-derived metawackes. In addition to these units, protomylonites derived from granitic, gabbroic and supracrustal rocks (marbles, metawackes) are found locally within the shear zones.

Ayer (1979) interpreted many of these fine-grained rocks as metavolcanics of andesitic and dacitic composition, and postulated the presence of a volcanic centre in the Pringle-Mazinaw Lake area. Primary textures indicative of a volcanic origin are absent in these rocks, and many of the breccias shown on Ayer's (1979) map were mapped by the authors as metaconglomerates derived from the Norway Lake granite or as intrusion breccias. Rocks mapped as basaltic andesites by Ayer (1979) have the chemical signature of Killer-type gabbros (Ayer 1979, Table 4), and remapping of the sample sites indicates that they are either hosted in protomylonitic Killer-type gabbro or in mafic gneisses adjacent to Killer-gabbro pods within the shear zones. It should be noted that when Ayer (1979) conducted his mapping, ductile mylonite zones had been little studied, and were poorly documented from the Grenville Province. Hence, interpretation of the fine-grained rocks present in the Shabomeka and Swamp Lake shear zones as metavolcanic rocks was reasonable at that time. In summary, although some of the rocks present in the Pringle-Mazinaw Lake area may at one time have been intermediate to felsic volcanics or volcaniclastic sediments, intense mylonization in this area has destroyed primary textures in these rocks making protolith identification problematical.

Grenville Supergroup Supracrustal Rocks

Metasedimentary supracrustal rocks predominate in the Mazinaw Terrane in the map area, and consist mainly of calcitic and dolomitic marbles, metawacke, and semipelite. Other rock types include minor feldspathic litharenite, calcareous meta-arenite, metapelite (generally alumina-poor), calc-silicate rocks, and intercalated calcitic marbles and metapelite and metawacke. Deformation and two regional metamorphic events have destroyed most primary textures in these rocks, although graded bedding is locally preserved in the thicker metawacke sequences. Stromatolites were not idenitified in any of the marbles, although Moore and Morton (1986) reported stromatolites at Marble Lake. Dolomitic marbles in the area are generally thinly layered and fine grained and, in many instances, are found adjacent to or within the Swamp Lake shear zone. Dolomitization in these areas may be related to shearing, and not original depositional processes.

Metaplutonic Rocks

The oldest metaplutonic rocks in the Mazinaw Terrane in the map area are metatonalites and metagranodiorites and associated intrusion breccias composed of metatonalite "matrix" and amphibolite, para-amphibolite, or Killer-type metagabbro "clasts". These older rocks do not form any coherent masses, but occur as lenses, belts, and layers within, and along the margins of, the younger granitic masses that underlie most of the northern part of the terrane. Only the larger of these older metaplutonic masses are indicated in Figure 3. The intrusion breccias locally show evidence of folding and shearing which is not always reflected in cross-cutting granitic dikes.

The most abundant metaplutonic rocks in the map area are the fine- to medium-grained, heterogeneous granites of the Abinger and Norway Lake granites (Figure 3). Muscovite is prevalent throughout these granite rocks, and may be a product of igneous crystallization, or M_2 metamorphism. The Abinger granite (Hewitt 1964, Rivers 1976) is also known as the Mazinaw Lake granite. The original term Abinger is preferred here because the granite underlies large tracts of Abinger township and the term better reflects the distribution of this plutonic body. These granites intrude the older tonalitic and gabbroic rocks in the map area, as well as all supracrustal rocks older than the Flinton Group.

The granites may have been intruded as a series of closely spaced sills. This would explain the local heterogeneity present within the granite, as well as the presence of mappable screens of older country rock throughout the Abinger granite. It is also consistent with the preservation of large areas of granodiorite and tonalitic intrusion breccias within the granites. Gossans are locally developed along granite-country rock contacts and in granitic intrusion breccias (*see* Economic Geology).

The age of these granitic rocks is not well constrained. Lumbers et al. (1990) correlate the Abinger granite with the 1245 Ma (van Breemen and Davidson 1988) Addington Granite (alaskite suite of Lumbers et al. 1990). Bell and Blenkinsop (1980) however report a whole-rock Rb-Sr age of 1185±25 Ma from the Abinger granite. This age could be either an emplacement age, or a metamorphic age (M_1). If an emplacement age, then the Abinger granite may be related to the *ca.* 1180–1160 Ma granite-syenite-monzonite suite of the Frontenac Terrane. It is noteworthy that Kinsman and Parrish (1990) reported an abundance of *ca.* 1160 Ma zircon detritus in Flinton Group metaquartzarenites just south of the map area. As the Flinton Group is in part locally derived (Moore and Thompson 1972, 1980; also *see* below), metaplutonic rocks of *ca.* 1160 Ma might be expected in the map area.

A variety of metamorphosed dike rocks are present in the map area, cutting all rock units except the Flinton Group. These include metagabbro dikes, metadiabase dikes, quartz feldspar porphyry dikes and plagioclase-porphyritic mafic dikes. The latter have locally been interpreted as plagioclase-porphyritic metabasalts where they intrude mafic gneisses (e.g., Ayer 1979; Rivers 1976), however, they clearly cut marbles in the area, and are less deformed than the supracrustal rocks they cut.

Flinton Group

INTRODUCTION

Moore and Thompson (1972, 1980) and Thompson (1972) described the Flinton Group as an unconformable sequence overlying the Grenville Supergroup and formally defined four formations within the Flinton Group. Three of these formations, the Bishop Corners, Myer Cave, and Fernleigh formations crop out within the map area. Within the map area, the Flinton Group strata are located in a 0.5 to 2 km wide east-northeast-trending belt, the Fernleigh belt (Figure 3) and in several discontinous belts marginal to the Norway Lake granite (Figure 3).

Moore and Thompson (1972, 1980) and Moore and Morton (1986) describe the Fernleigh belt as an overturned, tight to isoclinal syncline. Stratigraphic units are not repeated across the syncline and Moore and Thompson (1972, 1980) invoked rapid lateral facies changes across the Flinton Group in order to explain this lack of stratigraphic repetition. Rivers (1976), in studying the Fernleigh belt in the Fernleigh-Ompah area, found no evidence that it was a syncline, or even synformal, and concluded that it was a steep, southeast-facing overturned homoclinal sequence. Our mapping in the Bishop Corners to Fernleigh part of the belt confirms Rivers' (1976) interpretation. For example, south of Myer Cave, recent road construction has exposed an almost continuous section through the Myer Cave Formation. Marble breccias within the Myer Cave, in this section, fine upward, and are overlain by pelites characteristic of the uppermost Myer Cave Formation (member iva, see below). Thus, the stratigraphy exposed here appears to be a continuous, northwest-dipping, southeast-facing homoclinal sequence, and there is no stratigraphic or structural evidence for a synclinal or synformal structure as far west as Marble Lake even in the southern, less deformed and metamorphosed part of the Fernleigh Belt.

SUBDIVISION OF THE MYER CAVE FORMATION

The Myer Cave Formation can be divided into four members within the map area. From oldest to youngest, these newly defined members are: i) a *Laminated Schist member* consisting of finely laminated, graphitic schists with pyrite laminae, a thin (3 to 15 m thick) dolomitic marble horizon is present at the base of this member; ii) a *Calcareous member* consisting of fetid, thinly bedded, calcitic marbles interbedded with finely laminated, graphitic schists. Relatively schist-free horizons, 10 to 50 m thick, of calcitic marbles are present within this member; iii) an *Unlaminated Schist member* consisting of poorly to unbedded graphitic schist containing disseminated pyrite stringers. The *Unlaminated Schist member* grades into the Fernleigh Formation over a distance of about 15 m; iv) a *Pelite member* consisting of homogeneous, graphitic, staurolite + (chloritoid at lower grade) + garnet + biotite pelite; and ivb) a *Megabreccia member*, found only in the Myer Cave to Green Bay area containing blocks (0.3 to 10 m in length, 0.2 to 5 m in width) of dolomitic and calcitic marble derived from the Grenville Supergroup, and thinly bedded calcite marble blocks derived from the Calcareous member with either a graphitic pelite matrix similar in composition to the pelite member (iv) or a calcareous matrix. This megabreccia is a primary depositional feature, and not due to later tectonism.

FLINTON GROUP CORRELATIVES OVERLYING THE NORWAY LAKE GRANITE

South of Sand Lake, the Norway Lake granite is rimmed by a granite boulder cobble metaconglomerate correlated with the Flinton Group (herein and Moore and Thompson 1980). Smith (1958) originally described the contact as an unconformity, but later (Smith et al. 1969) described the contact as intrusive, in part because modal analyses of granite cobbles showed the cobbles contained less microcline than the granite. The subangular to subround cobbles decrease in size away from the granite, and the distribution of pelitic and arkosic facies intercalated with the conglomerate horizons are consistent with the granite cobbles being derived locally from the granite. The modal data of Smith et al. (1969) may simply reflect preferential weathering of potassium feldspars in the granite prior to and during deposition.

Field party personnel, in remapping this area, found that the metaconglomerate was interbedded with feldspathic metalitharenites and meta-arenites as well as metapelites containing microcline and garnet porphyroblasts and sillimanite. Kyanite may also be found at scattered localities in these rocks. These additional lithologies are similar to Flinton Group metapelites from classic Flinton Group lithologies (Bishop Corners pelite and Lessard Formation psammite), and further support the correlation of the Sand Lake metaconglomerate with the Bishop Corners Formation of the Flinton Group. In addition to this previously described locality, several other conglomerate and pelite horizons occur along the length of the Norway Lake granite in the area (*see* Figure 3). All show similar relationships to the granite, containing varied amounts of granite boulder metaconglomerate, feldspathic metalitharenite and metapelitics. These supracrustal rocks are discordant with respect to underlying rocks, generally tectonites related to the Shabomeka and Swamp Lake shear zones. All these metaconglomeratic and metapelitic units are correlated with the Bishop Corners Formation.

MAP PATTERN AND STRUCTURAL RELATIONS WITH UNDERLYING UNITS

The structural relationship between the Flinton Group and the underlying Grenville Supergroup and metaplutonic rocks presents many incongruities which are currently not well understood. For example, Moore and Thompson (1972, 1980) noted that the Flinton Group is preserved in tight, isoclinally folded synclines throughout the Mazinaw Terrane. However, where unconformable relationships are best developed with underlying units (Sand and Norway Lake areas, Kaladar metaconglomerate), synclines are not present, and the overlying metaconglomerates have a tabular form that mimics topography. Another incongruity is that the penetrative fabric in the Flinton Group appears to be better developed in the Flinton Group than in underlying units. In the Sand Lake area, at the granite-conglomerate contact, the penetrative foliation in the Flinton Group dips shallowly to the southeast at roughly 20° to 30°. This fabric is not readily apparent in the structurally and topographically underlying granite, yet, within the Flinton Group, steepens to 70° to 80° only a few tens of metres to the southeast. However, the map pattern and facies distribution within the Flinton Group at this locality is suggestive of a thin, tabular body that overlies underlying strata, which is visible in topographically low lying "windows". Similar relationships are present in the vicinty of the Dome gold occurrence in the Marble Lake area (Moore and Morton 1986). Thus, the map pattern seems inconsistent with the penetrative fabric. Similarly, in the Fernleigh belt, particularly along the southeastern contact of the belt, the penetrative fabric is inconsistent with the map pattern. As noted above, the sequence appears to be a steeply dipping homocline. If the penetrative fabric reflects the true attitude of the Flinton Group strata, then the contact with the Grenville Supergroup must be a fault, either downthrown to the north or an oversteepened thrust. There is no indication of a fault along this contact, and the map pattern of the Flinton Group in the Fernleigh belt in the Marble Lake area has the appearance of a thin, tabular, cover sequence. One possible explanation is that the penetrative fabric observed in the Flinton Group developed early during M_2 prior to major metamorphic mineral growth and that fabric development in the underlying strata was inhibited by the previous high-grade metamorphism (M_1) imposed on these rocks. Consequently, the penetrative fabric in the Flinton Group is restricted to the Flinton Group, and does not reflect regional structures, and that the map pattern of the Flinton Group more accurately reflects its unconformable, cover relationship to the underlying strata.

GEOCHEMISTRY

A persistent problem in regional stratigraphic mapping in the Mazinaw Terrane is distinguishing Flinton Group and Grenville Supergroup rocks in areas where metaconglomerates or aluminous pelitic rocks are absent. For instance, along the southeast flank of the Fernleigh Belt, it is difficult to distinguish between calcitic marbles and interlayered schists of the *Calcareous member* of the Myer Cave Formation from calcitic marbles of the Grenville Supergroup. North of Fernleigh, Bishop Corners pelite is in contact with epidote-bearing semipelitic rocks. These rocks are tentatively assigned to the Grenville Supergroup because they lack the aluminous metamorphic minerals present in Bishop Corners and Myer Cave formation pelites at Fernleigh. Both examples illustrate the difficulties found in defining the Flinton Group–Grenville Supergroup contact in many parts of the Mazinaw Terrane. It has been previously noted (Thompson 1972; Rivers 1976; Easton 1988, in press) that tourmaline is an abundant and ubiquitous accessory mineral within the Flinton Group, and field party personnal collected a suite of representative samples to determine if a reliable chemical screen could be developed to aid in stratigraphic assignment of the Flinton Group. Results were unavailable at the time of writing.

DEPOSITIONAL SETTING OF THE FLINTON GROUP

Moore and Thompson (1972, 1980) suggested a fluvial environment for deposition of the coarse clastic units of the Flinton Group and a shallow marine setting for the pelitic and carbonate units, both occurring in an extensional environment. We postulate that the Flinton Group was deposited in a fluvial-lacustrine environment, with deposition in part

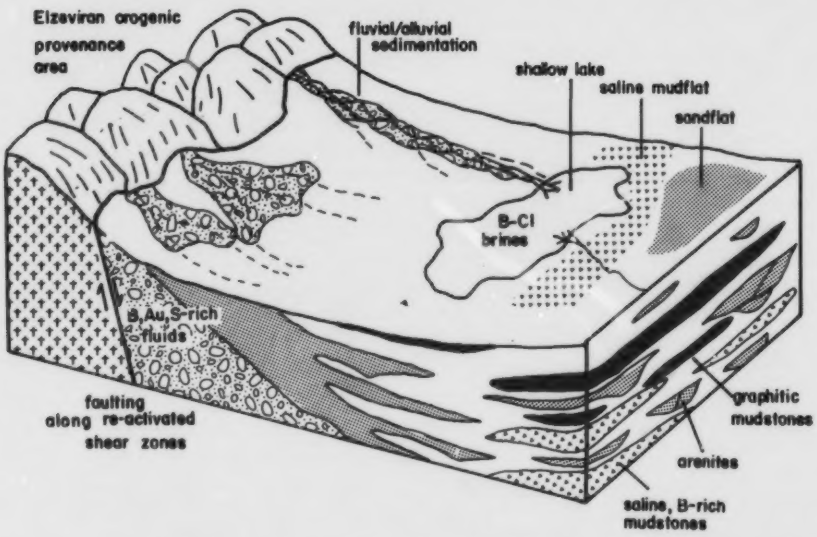

Figure 5. Sketch showing possible depositional environment of the Flinton Group in arid, rift valley basins. Basin faults are localized along older shear zones. Mineralization in and near the Flinton Group is enhanced by the presence of organic-rich mudstones, boron-chlorine-sulphate-rich brines related to playa lakes, source of metals in volcanic-derived clastic metasediments. Carbonate rocks are deposited in larger lakes or by later marine transgression (modified from Flint 1989).

controlled by rift valleys, which resulted in longitudinally oriented alluvial-fan and braided-stream trunk systems (Figure 5). This model explains the preservation of the Flinton Group in synformal, linear belts, as well as the localized faulting present along the Flinton unconformity, and associated mineralization. The alternating pelite-carbonate beds within the Fernleigh Formation may reflect annual variations in sediment supply into the rift valley lakes, and the ubiquitous and abundant presence of tourmaline thoughout the Flinton Group (e.g., Thompson 1972; Easton 1988) would be expected in an arid, fault-controlled depositional environment. The Myer Cave Formation megabreccia unit probably formed by collapse of a cliff into a lake, allowing for the incorporation of Myer Cave Formation and Grenville Supergroup blocks in a pelitic matrix. This model has metallogenic implications. Quartz-sulphide-carbonate veins, containing a variety of metals, including Au, Cu, Pb, Zn and As, are commonly found near the Flinton Group unconformity, although many are hosted entirely in Grenville Supergroup strata. The depositional setting of the Flinton Group outlined herein is similar to that described by Lefevbre (1989) for the Zambian copper deposits, as are the metal associations (Au, Cu, Pb, Zn and As). Mineralization is the result of fluid movement along fault systems, with fluid flow localized in permeable units below, along, and above the unconformity. In addition, black shales deposited in anoxic lakes are also locally mineralized (e.g., laminated sulphide schists of the Myer Cave Formation).

North-Northwest-Trending Faults

North-northwest-trending faults are prevalent throughout the Mazinaw Terrane in the map area, but are most prevalent near the Mazinaw–Elzevir Terrane boundary (Figure 3). Both right- and left-lateral faults are present, and sizable offsets are present; 500 m along the left-lateral fault through Mazinaw Lake and 500 m along the right-lateral fault running along the east shore of Joeperry Lake (Figure 3). Although the existence of this fault set had been recognized previously (e.g., Plevna Fault, Smith 1958, Pauk 1987), the abundance of faults of this trend in the area, and the scope of movement along them was previously unknown. At present, these faults are not known to have any economic significance, although the development of hematite, chlorite, and epidote is common in rocks located adjacent to these faults. In addition, talc is developed locally in the margin of the Joeperry Lake metagabbro where it is cut by the Joeperry Lake fault (Figure 3).

Mazinaw–Elzevir Terrane Boundary

Due south of the map area, the Mazinaw-Elzevir Terrane boundary is a narrow shear zone, marked by the development of straight gneisses. In the map area, however, the trace of the boundary is more difficult to ascertain, largely because north-northwest-trending faults run subparallel to the boundary (Figures 2 and 3). The boundary is still recognized by the following criteria: 1) changes in structural orientation from northerly and northeasterly trends in the Grimsthorpe domain to easterly trends in the Mazinaw Terrane; 2) the presence of granitic dikes and granitic plutons within the Mazinaw Terrane which are absent from the Grimsthorpe domain; 3) the development of biotite in mafic metavolcanic and metaplutonic rocks in the Mazinaw Terrane; and 4) increased deformation and higher metamorphic grade within Mazinaw Terrane rocks. Metagabbroic and metatonalitic rocks are found in both terranes, however calcitic and dolomitic marbles, siliceous clastic metasedimentary rocks, diverse metavolcanic sequences and the Flinton Group are all absent from the Grimsthorpe domain.

Mazinaw–Bancroft Terrane Boundary

Near the north boundary of the area, the Abinger Granite is in fault contact with the Bancroft Terrane. The Bancroft Terrane north of the map area consists of a sequence of marble tectonic breccias containing abundant amphibolite blocks and intercalated horizons. Along the map area boundary, the Bancroft Terrane consists of a sequence of thinly layered, locally migmatitic, para-amphibolite and metawacke units, locally with intercalated coarse-grained calcitic marble layers. Metamorphic grade appears to be higher on the Bancroft Terrane side of the boundary, although this is not well constrained by mineral assemblages mapped in the field. The boundary is marked by a 250 to 750 m thick zone of straight gneisses of intermediate composition, which are probably derived from tonalitic and granitic rocks found south of the boundary and para-amphibolites to the north. The straight gneisses are older than M_2, as flattened quartz lenticles within the straight gneisses have been recrystallized into equant quartz grains. Recrystallization has also increased the mean grain size of the straight gneisses, although the thinly laminated character of these rocks still persists. The straight gneisses dip to the north at 25° to 30°.

ECONOMIC GEOLOGY

Assay Results

Field party personnel collected samples for assay from a variety of rock types within the map area. Table 1 presents the results of some of these assays. Data can be grouped into 6 categories: assays from Flinton Group metasediments; assays from gossans in metaplutonic rocks, mainly the Abinger granite; assays from shear zones; assays from quartz-tourmaline veins; assays from metagabbroic rocks; and assays from miscellaneous samples.

Assays from gossans within the Abinger granite show local enrichments of a variety of metals, most notably copper and lead. The discontinuous and narrow nature of these gossan zones indicates that they have limited economic potential.

Gold

RELATIONSHIP TO SHEAR ZONES

Figure 4 shows the distribution of gold occurrences in the area. All known deposits are located within the Swamp Lake shear zone, and occur in two settings. First, gold is hosted in concordant to subconcordant veins in dolomitic marbles of the Grenville Supergroup (e.g., Star Mine, Boerth Mine) or the Flinton Group (e.g., Hardie Property). These veins have tremolite-actinolite reaction rims that have developed along the vein-marble contact, and contain chalcopyrite or tetrahedrite, with minor bornite, sphalerite, pyrite and arsenopyrite. At the Star Mine, chalcopyrite is also disseminated within the marbles. Second, gold is found in cross-cutting quartz-tourmaline veins that cut the dolomitic marbles and other lithologies (Bishop Corners Formation at the Hardie Property; sheared mafic and quartzofeldspathic gneisses at the Star Mine; and sheared granites and dolomitic marbles at the Big Dipper mine).

QUARTZ-TOURMALINE VEINS

Observations made by field party personnel place constraints on the timing of intrusion of quartz-tourmaline veins in the area. At the Star Mine, the veins cut sheared felsic gneisses, and have bleached the wall rocks up to 15 cm away from the veins, indicating that the veins are post-M_1 and post-D_1. The felsic gneisses contain recrystallized quartz lenticles, as do the veins, indicating that the veins developed either pre- or early-syn-M_2. South of Sand Lake, quartz-tourmaline veins cut Flinton Group metaconglomerates and have bleached wall rock around the veins. Further, tourmaline crystals pervade Flinton Group strata adjacent to the veins. Thus, the veins are also post-Flinton Group deposition. South of Sand Lake, the largest quartz-tourmaline veins (30 to 100 cm wide) are localized at the Norway granite—Flinton Group contact. Also in this area, two dominant vein trends are present, 130°/70° and 160°/75°. Barron (1983) reports concordant quartz-tourmaline veins at the Hardie Property, and that the highest grade mineralization on this property was reported in the quartz-tourmaline veins (5.70 ounce Au per ton). Concordant quartz-tourmaline veins have been observed by field party personnel within felsic gneisses of the Shabomeka shear zone. Wall-rock alteration has not been documented from the concordant veins, however, the concordant veins observed by field party personnel are narrow (<2 cm), and thus, such alteration may be poorly developed. The wide range in vein types and vein thickness suggests that the veins followed existing weakness in the rocks, and were not influenced by a regional stress field. The M_2 stress field was isotropic as demonstrated by porphyroblastic minerals in Grenville Supergroup and Flinton Group rocks. Assays from some quartz-tourmaline veins in the area are reported in Table 1.

ASSOCIATION WITH FLINTON GROUP

Both vein types at the Hardie Property are hosted in Flinton Group strata. The Star Mine is hosted in deformed Grenville Supergroup strata, and is about 1 km from the nearest Flinton Group rocks. The Big Dipper Mine is hosted in sheared rocks at the southern margin of the Norway Lake granite, about 500 m south of a Flinton Group metaconglomerate and metapelite belt. The Boerth Mine is hosted in deformed Grenville Supergroup rocks, however, it too is only a few hundred metres distant from Flinton Group outcrops. It is difficult to assess the significance of the proximity of the deposits to the Flinton Group unconformity. Did the existence of a pre-existing shear zone influence deposition of the

Flinton Group, and thus, the association is only coincidental? Or did the unconformity surface focus fluid flow during reactivation of the shear zone during Flinton Group deposition and subsequent metamorphism, thereby localizing gold-bearing quartz-tourmaline veins in basement and cover rocks located near the unconformity?

South of the map area, along Flinton Creek and in the Harlowe area, gold deposits are also associated with the Flinton Group unconformity. The Dome occurrence is hosted in concordant quartz veins hosted in Grenville Supergroup dolomitic marbles immediately underlying the Bishop Corners Formation. Flinton Group strata in this area probably overlie an older shear zone developed in underlying mafic metavolcanic rocks. At the Addington Mine, Bishop Corners Formation metaconglomerates unconformably overlie an older shear zone developed in mafic metavolcanic rocks. In this instance, carbonate rocks are not present, suggesting that the presence of dolomitic marbles may not be a critical factor in siting gold mineralization. Rather, the existence of an older shear zone with overlying Flinton Group rocks is probably the key factor.

GOLD MINERALIZATION AND METAMORPHIC GRADE

Apart from the Boerth Mine, and the James and Webber properties to the northeast (Figure 4), most gold deposits present in the map area, and to the south, are located near the greenschist-amphibolite facies transistion.

GUIDELINES FOR GOLD EXPLORATION

Gold deposits in the map area are associated with the shear zones developed in pre-Flinton Group strata in the area. Historic occurrences are commonly hosted in dolomitic marbles present within or adjacent to the shear zones. Gold is also found in quartz-tourmaline veins cutting both basement and Flinton Group rocks in proximity to the shear zones, and the largest veins are located near the unconformity surface Flinton Group. To date, all occurrences in the map area are localized in the Swamp Lake shear zone, particularly in the lower metamorphic grade segment of it. It is not known if the lack of occurrences along the Shabomeka shear zone reflects lack of exploration, the lack of dolomitic horizons within the shear zone, the paucity of Flinton Group strata along the shear zone, or higher metamorphic grade.

Sulphide Mineralization in the Flinton Group

Assays from strataform pyrite layers within Myer Cave Formation graphitic schists show little enrichment in gold, copper, nickel or lead, suggesting few other metals are associated with pyrite in these schists (Table 1). Similar pyritic schists in the Sulphide–Hungerford area in the Clare River area were mined for pyrite in the early 1900s. Cross-cutting sulphide veins in the Myer Cave Formation, however, show considerable enrichment in Zn and minor Pb enrichment (analyses 91RME–1012A, –1012B, Table 1).

Skarn Mineralization

A skarn is developed within a contact aureole developed around the northern tip of the Norway Lake granite where the granite intrudes calcitic marbles (Figure 3). The skarn zone extends for 500 to 750 m outward from the granite contact, and consists of a fine-grained diopside-epidote-plagioclase-calcite rock which locally contains large randomly oriented porphyroblasts of garnet or tourmaline which grew during M_2. The skarn zone is locally unconformably overlain by Flinton Group metapelites. Mineralization in the skarn zone consists of a contact metasomatic iron deposit (Figure 3) which has been trenched. The trench measures 2 by 5 by 3 m, and a sizable dump is present. No assessment work is available on this deposit (Assessment Files Research Office, Toronto, and Southeastern Resident Geologist's Office, Tweed). Sample 91RME–170 (Table 1) is from the dump. Samples 91RME–171 and 91RME–2133 are from skarn rocks. This is one of the few contact metasomatic skarn deposits known from the Mazinaw Terrane (*see* Carter 1984; Easton, in press).

Magnetite and Chromite in Metagabbroic Rocks

Easton and Ford (1990) reported enrichments in magnetite and chromite in rocks of the Killer Creek Gabbro Suite, particularly the hornblendite and melanocratic gabbro phases. Equivalents of this suite in the Mazinaw Terrane are similarly enriched in these elements. The most significant accumulation is located northeast of Joeperry Lake in Bon Echo Provincial Park, where a significant aeromagnetic high (GSC 1952) is underlain by a body of melanocratic metagabbro of the Killer Creek Gabbro Suite containing abundant hornblendite pods. Assay sample 91RME–060 (Table 1) is from one of these pods, and shows elevated concentrations of Cr and V. The high Ti contents of the Killer-type gabbros suggests the presence of ilmenite as well. The Joeperry Lake metagabbro has a fine-grained phase of chlorite + hornblende + magnetite around its margins, which may be the product of metamorphic reaction related to fluid interaction with surrounding rocks during M_2. This magnetite-rich rim may be largely responsible for the intense aeromagnetic signature of this body which is atypical of the suite elsewhere in the Grimsthorpe domain or the Mazinaw Terrane.

Industrial Minerals

Relatively pure dolomite marble occurs along the north (UTM 18T, 339275E 4977100N) and south shore (LeBaron and MacKinnon 1990) of Sand Lake. Kyanite, garnet and sillimanite occur throughout the Flinton Group, and are best developed in the eastern part of the map area where metamorphic grade is highest. The Clarendon Township sillimanite occurrence is located about 5 km east of the map area (Pauk 1987). However, the paucity of metapelitic units within the

Table 1. Assay results from samples collected by field party personnel from the Mazinaw area. All analyses by Geoscience Laboratories, Ontario Geological Survey.

Sample Number	UTM Coordinates	Au (ppb)	Cu (ppm)	Zn (ppm)	Other (ppm)	Comment
Flinton Group Metasediments and Cross-Cutting Sulphide Veins						
91RME-0083	334979E 4968991N	4	33	104	—	lower Myer Cave Fm., 15% pyrite in beds
91RME-0095	341812E 4973499N	—	—	—	—	upper Myer Cave Fm.
91RME-0096	340460E 4972460N	—	—	—	—	upper Myer Cave Fm.
91RME-0099	339020E 4971905	—	—	—	—	dol.-cc. marble, pit, Hardie property
91RME-0109	342119E 4973657N	—	—	—	—	upper Myer Cave Fm.
91RME-0133B	357109E 4985658N	<2	220	<10	—	Myer Cave Fm., with diss. sulphides
91RME-1002	338820E 4971730N	<2	33	148	Ni=26	lower Myer Cave Fm.
91RME-1004	338150E 4971040N	<2	75	20	Ni=95	Myer Cave Fm. cc. marble, quartz boudins
91RME-1008	339720E 4971770N	<2	30	109	—	lower Myer Cave Fm., 5% pyrite in beds
91RME-1012A	340460E 4972460N	<2	121	1400	Ni=295, Pb=73	cross-cutting sulphide vein, Myer Cave Fm.
91RME-1012B	340460E 4972460N	<2	440	1600	Ni=170, Pb=76	cross-cutting sulphide vein, Myer Cave Fm.
91RME-1012C	340460E 4972460N	<2	49	183	Ni=43	lower Myer Cave Fm.
91RME-1015	341812E 4973499N	11	167	136	Ni=187	cross-cutting sulphide vein, Myer Cave Fm.
91RME-1024	341750E 4973460N	4	40	95	—	Myer Cave Fm.
91RME-1026	337710E 4970860N	18	17	19	Ni=79, Pb=19	Myer Cave Fm., pyrite nodule
91RME-1124	343730E 4974280N	<2	—	—	—	plag-qtz-musc-py vein, Myer Cave Fm.
91RME-1125	343760E 4974445N	<2	—	—	—	lower Myer Cave Fm.
91RME-2146	340520E 4976000N	—	—	—	—	diss. sulphide in Bishop Corners pelite, Sand Lake area
91RME-2147	340680E 4975990N	17	875	100	—	diss. sulphide in Bishop Corners pelite, Sand Lake area
Gossan Zones in Metaplutonic Rocks						
91RME-0004	334887E 4986908N	<2	330	26	Ni=29	rusty quartz vein, Abinger Granite
91RME-0011	335660E 4982540N	<2	580	20	Ni=56	calc-silicate xenolith, Abinger Granite
91RME-0014	335450E 4983430N	10	8	41	—	diss. sulphide in monzonite, Abinger Granite
91RME-0017	335800E 4982180N	<2	64	49	Pb=275	diss. sulphide in monzonite, Abinger Granite
91RME-0200A	327700E 4972800N	—	—	—	—	yellow-white gossan, Abinger Granite
91RME-0200B	327700E 4972800N	107	7	26	—	black-white gossan, Abinger Granite
91RME-0200C	327700E 4972800N	—	—	—	—	sulphides in quartz vein, gossan zone in Abinger Granite
91RME-2005	336850E 4982270N	<2	12	63	—	py in metased. xenolith, Abinger Granite
91RME-2020	336850E 4981020N	<2	171	6	—	gossan, Abinger Granite
91RME-2025	337570E 4979380N	<2	30	11	—	gossan, Abinger Granite
91RME-2092	335260E 4978860N	<2	6	<10	—	sulphide in amph. xenoliths in tonalite intrusion breccia
91RME-2139	328090E 4971735N	<2	—	—	—	pyrite, Abinger Granite, cutting mafic xenolith
91RME-2148	326680E 4984250N	13	730	54	—	sulphide in amph. xenoliths in tonalite intrusion breccia
Samples from Older Shear Zones						
91RME-0031	325550E 4973120N	<2	10	14	—	Hematite-pyrite rock, Highway 41
91RME-0032	325440E 4973450N	<2	7	9	—	Highway 41
91RME-0178B	343380E 4980000N	200	585	110	—	py-po vein in mafic mylonite, Plevna
91RME-1104A	334130E 4977700N	35	51	17	—	altered & sheared, Big Dipper Mine
91RME-1104B	334130E 4977700N	19	91	13	—	quartz vein, dump, Big Dipper Mine
91RME-1126	341430E 4978000N	<2	—	—	—	mylonite derived from calc-silicates?
91RME-2060	334470E 4988680N	<2	43	19	—	py in quartz vein, sheared Abinger Granite
91RME-2104A	334000E 4974830N	<2	<5	92	—	epidotized mylonitic Abinger Granite
91RME-2104B	334000E 4974830N	<2	12	127	—	as above, less sheared
91RME-2112	329785E 4969060N	3	29	595	Pb=194	sheared dolomitic marble
91RME-2113	329755E 4969070N	13	6	39	—	sheared mafic mylonite
91RME-2128	340500E 4975100N	<2	—	—	—	calc-silicate/marble mylonite
91RME-2131	341030E 4975390N	<2	—	—	—	calc-silicate/marble mylonite
91RME-2142	330130E 4971490N	<2	—	—	—	altered felsic mylonite, near Buffadison prospect

Table 1 (continued). Assay results from samples collected by field party personnel from the Mazinaw area. All analyses by Geoscience Laboratories, Ontario Geological Survey.

Sample Number	UTM Coordinates	Au (ppb)	Cu (ppm)	Zn (ppm)	Other (ppm)	Comment
Quartz-Tourmaline Veins						
91RME-0097A	339300E 4972290N	—	—	—	—	malachite stain, pit, Hardie property, hosted in Bishop Corners meta-arenite
91RME-0143	331099E 4969526N	15	21	73	—	Star of East Mine, discordant vein
91RME-0144	331076E 4969547N	<2	<5	<5	—	Star of East Mine, discordant vein
91RME-0145	330979E 4969487N	225	<5	36	—	Star of East Mine, quartz-actinolite vein, subconcordant, in cpy-bearing dolomite marble
91RME-0157	332200E 4972975N	<2	10	41	—	concordant vein in felsic mylonite
91RME-0178A	343510E 4979750N	<2	—	—	—	vein cuts mafic mylonite, Plevna
91RME-0180	338900E 4975685N	<2	—	—	—	cuts granite-Flinton Gp. metaconglomerate contact, Sand Lake area
91RME-0185	341600E 4975860N	<2	—	—	—	hosted in Flinton Gp. metaconglomerate, Sand Lake area
91RME-0187A	340950E 4975790N	<2	—	—	—	hosted in Flinton Gp. metaconglomerate, Sand Lake area
91RME-0187B	340950E 4975790N	<2	—	—	—	disseminated tour. in Flinton Gp. metaconglomerate, Sand Lake area
Gabbroic and Ultramafic Rocks						
91RME-0060	318980E 4976480N	<2	32	175	Cr=970 Ni=240 V=725 Pt,Pd=<1 ppb	hornblendite, Bon Echo Provincial Park
91RME-0138	315199E 4973605N	39	26	92	—	metagabbro, diss. sulphide, SW Rainy Lake, Grimsthorpe domain
91RME-0162	324930E 4969770N	15	645	—	—	diss. sulphide, Pringle Lake area
91RME-1141	318800E 4976340N	49	12	155	Pd=125ppb Pt=67ppb Cr=1550 V=327	fine-grained, mt-rich altered hornblendite, Bon Echo Provincial Park
Miscellaneous Samples						
91RME-0038	324885E 4977525N	<2	7	14	—	fault gouge, Abinger Granite
91RME-0044	340065E 4976615N	4	33	104	—	hematite-chlorite marble, possible fault gouge
91RME-0124	332280E 4966089N	11	210	112	—	hematite-malachite dolomitic marble
91RME-0170	340870E 4975780N	—	—	—	—	massive magnetite from old pit
91RME-0171	340900E 4975880N	—	—	—	—	tourmaline-bearing skarn rock, Sand Lake area
91RME-0177	343430E 4980100N	4	—	—	—	py-cpy-sph? calcite marble, construction pit, Plevna schoolyard
91RME-1006	338580E 4971330N	<2	43	31	—	dolomite marble, possible fault zone
91RME-1006B	" " " "	<2	43	190	—	fault gouge derived from dolomite marble
91RME-1085	338940E 4973870N	<2	9	21	—	hematite-chloritized marble from construction pit, NNW-trending fault zone
91RME-1086	340720E 4978390N	6	23	180	—	gossan zone in metawacke
91RME-1119A	340640E 4976760N	<2	—	—	—	calc-silicate
91RME-1119B	" " " "	<2	—	—	—	hematite-chloritized marble
91RME-2026	337570E 4979350N	4	82	455	Pb=21	mafic volcanic metawacke with diss. sulphide
91RME-2133	340870E 4979350N	<2	—	—	—	garnet-epidote skarn rock, Sand Lake area

Detection limit for Au is 2 ppb, <5 ppm for Cu, Ni and Cr, and <10 ppm for Zn and Pb. Background levels in area are generally close to detection limits. All samples analyzed for Pb and Ni, only significant values reported. ND = not determined

Bishop Corners Formation in the map area, the graphite-sulphide-rich character of much of the Myer Cave Formation, limited folding of the Flinton Group in the area, and the lower metamorphic grade limits the kyanite-sillimanite-garnet potential of the map area. No building stone prospects have been documented from the map area (LeBaron et al. 1989).

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18. Geology of the Coldwell Alkaline Complex

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INTRODUCTION

This summary presents the results of the first field season of a three-year geological mapping and research programme on the Coldwell Alkaline Complex. The purpose of the project is: 1) to produce a 1:20 000 geological map of the Coldwell Alkaline Complex based on new mapping and compilation of previous geological and mineral exploration work; 2) to develop models for processes of concentration of rare elements (Nb, Ta, Zr, Y, REE) and base (Cu, Ni) and precious (Pd, Pt, Au) metals; and 3) to investigate the petrogenesis of alkaline magmatism during processes of continental rifting.

The 580 km² Coldwell Alkaline Complex, the largest alkaline intrusion in North America, is situated between the Pic and Little Pic rivers, on the north shore of Lake Superior, 275 km east of Thunder Bay. The town of Marathon is located within the eastern part of the Coldwell complex. The southern part of the complex can be easily accessed by Highway 17, the Canadian Pacific Railway and the Lake Superior shore. The Coldwell complex occurs at the junction of 4 NTS 1:50 000 map sheets: 42/D9, 42D/10, 42 D/15 and 42 D/16 (*see* Figure 1).

Geological mapping during the first field season focussed on the accessible southern part of the Coldwell complex. Mapping was completed along the Lake Superior shoreline, Highway 17, the Canadian Pacific Railway and electrical transmission lines. Limited bush traversing was completed in the south-east part of the Coldwell complex to complete two map sheets: OBM 20 16 5300 53900 and OBM 20 16 5500 54000. Significant base-metal and platinum-group-element (PGE) and rare-metal occurrences were sampled for geochemical analyses and petrologic studies. Representative samples of each of the rock units were also collected for geochemical and petrological research. The Geordie Lake (Cu-PGE) and the Marathon Niobium occurrences, which are not within the southern part of the complex, were also visited and sampled.

GENERAL GEOLOGY

The Coldwell Alkaline Complex (Figure 2) was emplaced into Archean rocks of the Wawa Subprovince of the Superior Province during the early stages of the Middle Proterozoic Midcontinent Rift at 1108 ± 1 Ma (Heaman and Machado

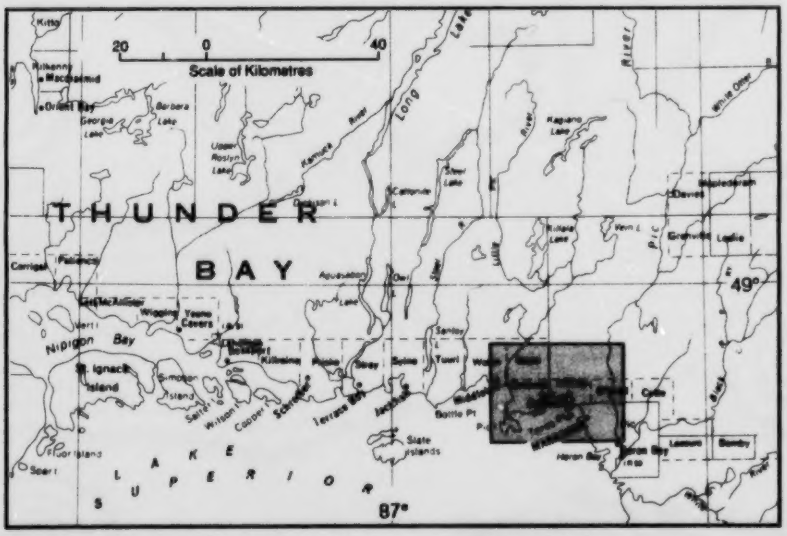

Figure 1. Location map of the Coldwell Alkaline complex, scale 1:1 584 000.

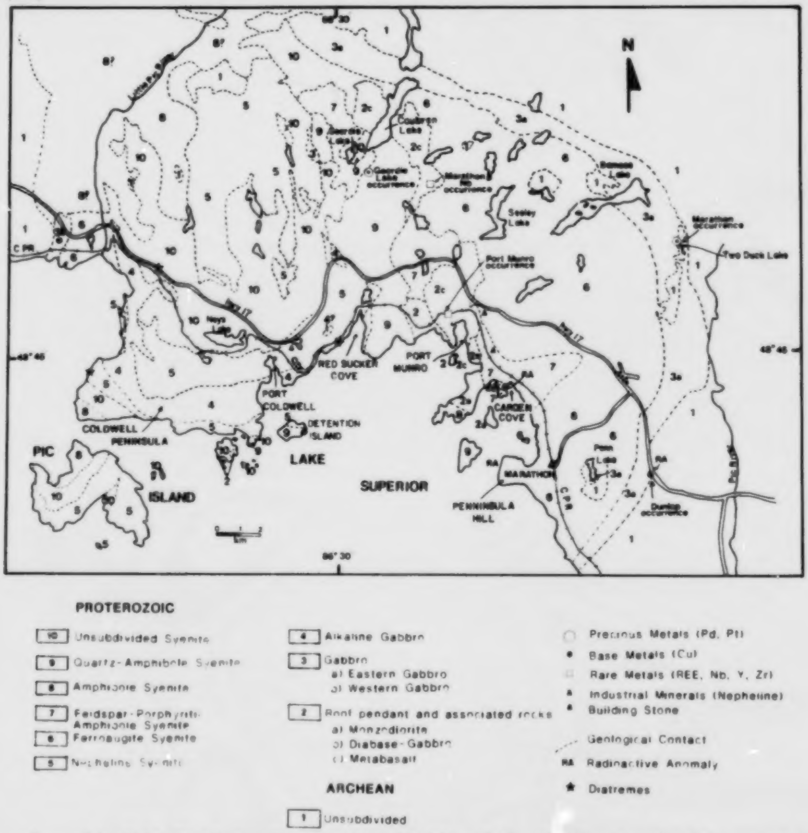
N
Geordie Lake
Coubran Lake
Geordie Lake occurrence
Marathon PGE occurrence
Seeley Lake
Bamoos Lake
Marathon occurrence
Two Duck Lake
Port Munro occurrence
Hwy 17
CPR
Hays Lake
RED SUCKER COVE
PORT MUNRO
PORT COLDWELL
DETENTION ISLAND
CARDER COVE
COLDWELL PENINSULA
PIC ISLAND
LAKE SUPERIOR
MARATHON
PENINSULA HILL
Penn Lake
Dunlop occurrence
Pic River
48°45
86°30
0 1 2 km
PROTEROZOIC
10 Unsubdivided Syenite
9 Quartz-Amphibole Syenite
8 Amphibole Syenite
7 Feldspar-Porphyritic Amphibole Syenite
6 Ferroaugite Syenite
5 Nepheline Syenite
4 Alkaline Gabbro
3 Gabbro
a) Eastern Gabbro
b) Western Gabbro
2 Roof pendant and associated rocks
a) Monzodiorite
b) Diabase-Gabbro
c) Metabasalt
ARCHEAN
1 Unsubdivided
Precious Metals (Pd, Pt)
Base Metals (Cu)
Rare Metals (REE, Nb, Y, Zr)
Industrial Minerals (Nepheline)
Building Stone
Geological Contact
RA Radioactive Anomaly
Diatremes

Figure 2. Schematic geology of the Coldwell Alkaline Complex. Simplified from Puskas (1967) and results of the present study.

1987). The Coldwell Alkaline Complex is located at the north end of the Thiel fault, a zone of faulting which separates grabens with different subsidence history in the rift (Cannon et al. 1989). A north-trending magnetic high links the rocks of the Coldwell Alkaline Complex with those of the Midcontinent Rift beneath Lake Superior.

Previous workers considered the complex to be a result of extensive fractional crystallization of a single batch of magma within a funnel-shaped intrusion (Lilley 1964) or lopolith (Puskas 1967). Later studies demonstrated that the Complex was not emplaced as a single batch of fractionated magma. Currie (1980) proposed a model in which the Coldwell Alkaline Complex developed from three intersecting systems of ring dikes and cone sheets, defined by igneous layering. Mitchell and Platt (1977, 1978) also propose that the Coldwell complex can be divided into three centres of alkaline magmatism, emplaced by cauldron subsidence associated with major faults.

Puskas (1967) produced a 1-inch-to-1/2-mile geological map of the Coldwell Alkaline Intrusion. This was followed by a compilation map by Currie (1980) which included results of limited field investigation. Subsequent research includes detailed petrological and economic geological studies including: mineralization within the Eastern Gabbro (Lum 1973; Wilkinson and Colvine 1978; Watkinson et al. 1973, 1983, 1986; Smyk 1986; Dahl, McGoran and Watkinson 1986, 1987; Dahl, Watkinson and McGoran 1987; Ohenstetter et al. 1989) and Geordie Lake gabbro (Mulja and Mitchell 1988, 1990; Good and Crocket 1989, 1990); petrology and mineral chemistry of the saturated and oversaturated syenites (Mitchell and Platt 1978; Currie 1980) and undersaturated syenites (Currie 1980; Mitchell and Platt 1982b); field guides (Puskas 1970; Mitchell and Platt 1977); radiometric surveys (Ford 1990); geochronology (Fairbairn 1959; Chaduri et al. 1971; Bell and Blenkensop 1980; Bell et al. 1979; Platt and Mitchell 1982; Heaman and Machado 1987); gravimetric studies (Corbett et al. 1967; Mitchell et al. 1983); paleomagnetism (Lewchuk and Symons 1990); and several graduate and undergraduate theses from Lakehead University (Lee 1971; Aubut 1977; Balint 1977; Jago 1980; McGill 1980; Kent 1981; Clark 1983; Laws 1983; Evans 1984; Laderoute 1988; Lukosius-Sanders 1988; Mulja 1989; McLaughlin 1990; Nicol 1990), Carleton University (Lum 1973; Wilkinson 1983), McMaster University (Herdman 1974; Whittaker 1979) and the University of Western Ontario (Leszczyszn 1959; Lilley 1964; McDougall 1985; Oliver 1987).

MINERAL EXPLORATION

Economic mineral occurrences in the Coldwell Alkaline Complex are subdivided into: base and precious metals, rare metals, building stone and industrial minerals.

The Eastern Gabbro of the Coldwell Alkaline Complex has been extensively explored for Cu, Ni and PGEs. From 1963 to 1967 Anaconda American Brass Limited explored the Eastern Gabbro from Bamoos Lake south to the Lake Superior shore for Cu and Ni. They completed 171 diamond-drill holes within the gabbro, intersecting mineralization with grades between 0.05 to 25% Cu. During the mid-1980s Fleck Resources Limited explored the gabbro for its Cu and PGE potential. Based on an additional 37 diamond-drill holes and extensive surface sampling, Fleck outlined 37 million tons of 0.31% copper, 0.04% nickel, 0.007 ounce per ton platinum, and 0.027 ounce per ton palladium (McGoran 1987).

PGE mineralization also occurs within the Geordie Lake Gabbro, discovered in the mid-1980s and explored and drilled by St. Joe Canada Inc..

Limited exploration for rare metals (Nb, Zr, Th, U, and Ce), has been done in the Coldwell Alkaline Complex. The Marathon and Port Munroe niobium properties are the two main occurrences. Grab samples from the Port Munroe occurrence are reported to have 1.35 weight % Nb_2O_5, 0.08 weight % U_3O_8, 3.00 weight % ThO_2, and 1.2 weight % Ce_2O_5 (Gustafson 1961) and the Marathon Niobium Property, 0.47 weight % Nb_2O_5 and 2.44 weight % ZrO_2 (Pye 1954).

Red and black ferroaugite syenite has been investigated as a potential building stone by Cold Spring Granite Company Limited in the late 1930s and again in the 1980s and by the Lake Superior Stone Syndicate in 1960.

Nepheline syenite immediately west of Red Sucker Cove was examined as a potential source of nepheline by Dennison Mines Limited in 1960. Bulk samples were collected and tested, however, it is reported that nepheline concentrates with iron contents below an acceptable level of 0.08 weight % FeO could not be consistently produced (Puskas 1967).

DESCRIPTION OF ROCK TYPES

Mitchell and Platt (1977, 1978) subdivided the Coldwell Alkaline Complex into three intrusive Centres: Centre 1 consists of the Eastern and Western gabbros, and ferroaugite syenite; Centre 2 is represented by nepheline syenite and alkaline gabbro, which occurs between Little Pic River and Red Sucker Cove; and Centre 3 consists of quartz-amphibole syenite which occurs west of Red Sucker Cove. Intrusive centres are defined by petrography and mineral chemistry; as a result, in the field it is not always possible to assign the syenites to specific intrusive centres. For the purposes of the present study subdivisions of the rocks based on the mineralogy and textures recognizable in the field, and contact relationships were developed. The mineralogy, textures and intrusive relationships for each of the rock types are summarized in Table 1.

Gabbroic Rocks

EASTERN AND WESTERN GABBROS

The Eastern and Western gabbros occur along the outer margin of the Coldwell Alkaline Complex, between Archean host rocks and later ferroaugite syenite. The Eastern Gabbro forms a crescent, which has a strike length of approximately 33 km, around the alkaline rocks which form the main part of the complex. The Western Gabbro which has a strike length of 2 km and a width of 700 m occurs at the west margin of the Coldwell Complex on the west side of the Little Pic River. The two gabbros are separated by a quartz-amphibole syenite which occurs in the northwest part of the complex. Both gabbros exhibit reversed magnetic polarity (Lewchuk and Symons 1990), a feature which is also observed in the lower part of the Keweenawan Supergroup (Halls 1978).

The Western Gabbro is extensively intruded by saturated to oversaturated and undersaturated syenites. Where syenite dikes and sills are common, the Western Gabbro is recrystallized and has a mottled pink-white colour. This is considered to be a result of extensive recrystallization and metasomatism caused by the intrusion of the syenites.

Mapping in the Eastern Gabbro has defined several major rock units. Massive magnetite-bearing, olivine gabbro containing biotite forms the lower part of the gabbro and is in contact with Archean rocks. In some areas, most notably around Two Duck Lake, there is a glomeroporphyritic diabasic gabbro which has lath-shaped phenocrysts of plagioclase. This diabasic gabbro is closely associated with the eastern contact of the gabbro where it occurs as xenoliths in later layered gabbros and as clasts in rheomorphic breccias which are common along the eastern contact with the Archean rocks.

The main part of the Eastern Gabbro has layering which is parallel to the eastern contact and dips at 20° to 50° toward the centre of the complex. The gabbro is generally coarse-grained with plagioclase, clinopyroxene, magnetite, olivine, apatite, biotite and minor amphibole. Toward the top of the section, magnetite increases in abundance while olivine and biotite decrease in abundance. The layers are defined by magnetite with minor olivine and form 2 to 3 cm thick melanocratic layers which can be traced for up to 85 m. Close to the east contact, the layers are widely spaced (approximately 1 m) and become more closely spaced towards the west. The gabbro at the west contact, with the ferroaugite syenite, is coarse-grained and massive with plagioclase, clinopyroxene and magnetite and traces of olivine and biotite.

Table 1. Summary of characteristics of rock units in the Coldwell Alkaline Complex. Centres are as defined by Mitchell and Platt (1977, 1982a).

Rock Type	Mineralogy	Texture	Intrusive Relations	Economic Associations	Centre (*)
Amphibole syenite	Kspar, amphibole quartz, magnetite	Massive, equigranular	Intrudes nepheline syenite ferroaugite syenite and Archean		3
Recrystallized Quartz Amphibole Syenite	Kspar, quartz, amphibole, magnetite	Massive, anhedral granular	Gradational with feldspar porphyritic amphibole syenite	Cu	3
Feldspar Porphyritic Amphibole Syenite	Kspar, plagioclase amphibole, magnetite	Massive to porphyritic	Intrudes roof pendant and ferroaugite syenite	Rare metals	1?
Ferroaugite Syenite	Albite, Kspar, amphibole, ferroaugite	Massive to well layered	Intrudes E & W Gabbro	Building stone	1
Nepheline Syenite	Plagioclase, Kspar amphibole, natrolite nepheline, biotite	Massive to well layered and foliated	Intrudes and brecciates alkaline gabbro	Industrial mineral potential	2
Alkaline Gabbro	Plagioclase, biotite olivine, clinopyroxene amphibole, magnetite	Massive, inclusion rich to well layered	Not known		2
Eastern and Western Gabbro	Plagioclase, olivine clinopyroxene, magnetite, amphibole, apatite, biotite	Massive to well layered to Archean pegmatitic	Intrudes	Cu, PGE	1
Roof Pendant		Massive, diabasic, to amygdaloidal		Rare metals in cross cutting syenite dikes	

Rock types are arranged in approximate order of intrusive sequence from oldest at base.
** Rock types are tentatively assigned to centres of Mitchell and Platt (1977, 1982a) for the purpose of correlation of study with previous work.*

In the Two Duck Lake area, a coarse-grained to pegmatitic gabbro intrudes the layered Eastern Gabbro. The coarse gabbro is composed of plagioclase, clinopyroxene, olivine, hornblende, apatite and biotite with up to 6% chalcopyrite. Pegmatitic zones have grains in excess of 6 cm and consists of plagioclase, olivine, clinopyroxene, hornblende and biotite with local concentrations of apatite and chalcopyrite. This younger gabbro, known as the Two Duck Lake gabbro, is the main mineralized rock in the Marathon Cu-PGE occurrence south of Bamoos Lake. Pegmatitic gabbro, similar to the Two Duck Lake gabbro has also been identified cutting the Eastern Gabbro along Highway 17 and cuts the Western Gabbro near the Lake Superior shoreline.

Rheomorphic breccia occurs sporadically along the east contact of the Eastern Gabbro. It is a brecciated Archean metavolcanic and/or metasedimentary rock with clasts ranging in size from 1 cm to almost 1 m. Clasts are rounded to subangular and commonly have thin (1 to 2 cm), recessively weathered reaction rims. In some cases granitic veinlets, interpreted to have formed by anatexis, occur around clasts. Locally this granitic material appears to have been mobilized and forms irregular feldspar porphyritic dacitic dikes which intruded the Archean rocks.

A small area of Archean metavolcanics, rheomorphic breccia and Eastern Gabbro outcrops around Penn Lake. These rocks are surrounded by ferroaugite syenite and are interpreted to be a xenolith in the syenite.

ROOF PENDANT AND ASSOCIATED ROCKS

A roof pendant with associated hypabyssal intrusive rocks approximately 14 km long and 4 km wide occurs east of the Red Sucker Cove lineament and west of Seeley Lake. The roof pendant is not continuous from north to south, but occurs in blocks in the order of 1 km to 100 m size, intruded by saturated to oversaturated syenites. The rocks of the roof pendant overlie the ferroaugite syenite.

Mitchell and Platt (1977, 1978) proposed that the Red Sucker Cove lineament is a major structural zone which has juxtaposed deeper crustal rocks to the west, with a higher structural level in the east. This sense of displacement provides an explanation for the preservation of the roof pendant east of the lineament.

The roof pendant and associated intrusive rocks consist of metabasalt, diabase, monzodiorite and gabbro. The eastern contact of the roof pendant and associated rocks is typically intruded, brecciated and extensively assimilated by feldspar porphyritic amphibole syenite and ferroaugite syenite. The contacts between the roof pendant and syenite are irregular but typically subhorizontal. The western contact between recrystallized quartz amphibole syenite and the roof pendant varies from sharp to gradational with gradational contacts characterized by progressive development of a red rim around feldspars in rocks of the roof pendant.

Metabasalts of the roof pendant are black, aphanitic and extremely fractured with rounded to elliptical epidote-quartz filled structures a few mm to 2 cm in size, which may be amygdules. Sharp contacts between amygdaloidal and massive zones are considered to be flow contacts. The flows are 30 cm to 5 m thick, and dip 08° SW. In the southernmost parts of the Coldwell Alkaline Complex, the metabasalts of the roof pendant exhibit textures which are flow breccias. These basalts are considered to be Proterozoic but further work is required to test this hypothesis.

Sub-ophitic diabasic gabbro overlies the metabasalt and displays an upward increase in grain size from fine-grained to medium-grained. This relationship suggests that the diabasic gabbro intruded into and chilled against the basalt. Within the central part of the diabasic gabbro, feldspar cores are altered to epidote, and epidote commonly fills fractures and vugs. Overlying this zone, feldspars become reddened and the sub-ophitic texture disappears. This reddened equigranular rock is monzodiorite and occurs close to the contact with the recrystallized quartz amphibole syenite.

The gabbro associated with the roof pendant occurs near Geordie Lake where it is is medium- to coarse-grained and in addition to pyroxene and plagioclase contains olivine, magnetite and apatite. The relationship of the gabbro to the other three units of the roof pendant will be investigated in subsequent mapping.

ALKALINE GABBRO

The alkaline gabbro follows the outline of Coldwell Peninsula where it forms a ring around nepheline syenite. However, no direct contact with the main unit of nepheline syenite is observed but there is contact with feldspar porphyritic and natrolite syenites.

At the contact, the alkaline gabbro is brecciated and assimilated by feldspar porphyritic and natrolite syenites. Clasts of alkaline gabbro in breccias exhibit both lobe and cuspate and sharp angular contacts with the intruding syenites. The relationship between the two different rocks may be one of assimilation and/or co-mingling magmas. On the west side of Red Sucker Cove, the alkaline gabbro is in contact with recrystallized quartz amphibole syenite.

The alkaline gabbro consists of several different subunits including gabbro, biotite gabbro, sheeted gabbro and inclusion-rich gabbro. The study of the alkaline gabbro is complicated by the pervasive recrystallization and metasomatism, resulting in the crystallization of amphibole, biotite and chlorite. Typically the gabbro is medium- to coarse-grained, melanocratic to mesocratic, with olivine rimmed by pyroxene and amphibole. Layering within the gabbro is rare and variable in strike and dip. Biotite gabbro is distinguished by the presence of coarse-grained poikilitic biotite which includes pyroxene and amphibole. Sheeted gabbro consists of alternating melanocratic, mesocratic and, locally, leucocratic gabbro. The inclusion-rich gabbro is texturally variable and contains abundant rounded to elliptical fine- to medium-grained inclusions in a leucocratic matrix. Inclusions range from a coarse-grained biotite gabbro to basaltic rocks. The inclusion-rich gabbro may intrude the alkaline gabbro.

Undersaturated Intermediate to Felsic Rocks

NEPHELINE SYENITES

A 10 km wide by 22 km long intrusion of nepheline syenite occurs between the Little Pic River and Red Sucker Cove. The nepheline syenite, along with the alkaline gabbro, form a ring structure.

The margin of nepheline syenite is intruded by a suite of undersaturated rocks which are variable in texture and mineralogy, but represented by two end-member compositions, a feldspar porphyritic syenite and natrolite syenite. These two rocks are similar to the syenites which intrude, brecciate and assimilate alkaline gabbro. Nepheline syenite is also intruded by amphibole syenite and quartz-bearing pegmatites.

Nepheline syenite varies from melanocratic to leucocratic, with the mesocratic variety being most common. The mesocratic nepheline syenite is typically medium-grained with more feldspar than nepheline and variable proportions of natrolite, biotite and amphibole. Locally, nepheline syenite is well layered, with melanocratic subunits grading into mesocratic subunits. The dips of the layering are toward the centre of the Coldwell complex. Feldspar porphyritic mafic inclusions, in which biotite is the dominant mafic mineral, form up to 20% of the nepheline syenite in some locations on the shore of Lake Superior.

Saturated to Oversaturated Intermediate to Felsic Rocks

Saturated and oversaturated syenites make up at least 75% of the Coldwell Alkaline Complex. The saturated to oversaturated syenites are divided into four texturally and mineralogically distinct subunits. Syenites not subdivided into specific subunits are described separately.

FERROAUGITE SYENITE

The ferroaugite syenite outcrops over an area of approximately 150 km² and dominates the eastern half of the Coldwell Alkaline Complex, occurring between the Eastern Gabbro and the rocks of the roof pendant. This rock type also occurs west of Little Pic River and east of the Western Gabbro.

Ferroaugite syenite typically has tabular to lath feldspars with interstitial ferroaugite, amphibole, olivine and aenigmatite (Mitchell and Platt 1978). Commonly the feldspars exhibit a blue iridescence produced by cryptoperthite. In hand specimen quartz is present, but rare. Most of the ferroaugite syenite is massive; however, near its base and within the central part of the unit, the ferroaugite syenite is well layered. The layering is defined by a greater proportion of ferromagnesian minerals, and varies from well-defined planar modal variation, dipping 25° to 45° to the west, to wispy convoluted layers. Toward the west contact the ferroaugite syenite changes in colour from black to red.

FELDSPAR PORPHYRITIC AMPHIBOLE SYENITE

The feldspar porphyritic amphibole syenite occurs between the ferroaugite syenite and the roof pendant.

This subunit contains two varieties which are separated by a sharp contact. The two varieties are: feldspar porphyritic amphibole syenite with a groundmass that varies from aphanitic to medium grained, and medium-grained amphibole syenite with columnar feldspar and interstitial amphibole. The medium-grained groundmass of the feldspar porphyritic amphibole syenite is indistinguishable from the columnar-feldspar amphibole syenite. The columnar-feldspar amphibole syenite intrudes the feldspar porphyritic amphibole syenite and both rock types intrude and assimilate the rocks of the roof pendant. The contact between these two syenites and the recrystallized quartz amphibole syenite appears to be gradational. Where feldspar porphyritic amphibole syenite is in contact with the ferroaugite syenite it is extensively veined by pegmatites.

AMPHIBOLE SYENITE

Amphibole syenite occurs between the western contact of the Coldwell Alkaline Complex, and Red Sucker Cove. In this area, amphibole syenite occurs as dikes which intrude and brecciate undersaturated, and saturated to oversaturated syenites. The amphibole syenite is an olive-brown to pink, leucocratic syenite with equant feldspars, variable amounts of quartz and abundant miarolitic cavities. Pegmatites are not evident within in the amphibole syenite.

There are numerous varieties of the amphibole syenite, and it has been suggested that many of the subunits are hybrid magmas (Lukosius-Sanders and Mitchell 1988).

RECRYSTALLIZED QUARTZ-AMPHIBOLE SYENITE

Recrystallized quartz-amphibole syenite occurs within the central part of the Coldwell Alkaline Complex. It is situated between the alkaline gabbro in the west, and the roof pendant and feldspar porphyritic amphibole syenite in the east.

Recrystallized quartz-amphibole syenite is red with a granular texture defined by medium-grained anhedral feldspar, quartz and green amphibole. In some areas, the recrystallized syenite has feldspar and amphibole phenocrysts.

UNSUBDIVIDED SYENITE UNITS

Between the Little Pic River and Red Sucker Cove, it is difficult to divide the syenites into specific subunits. These rocks require petrographic and geochemical data in order to define subunits and determine their genetic relationship with the other syenites.

Pegmatites

UNDERSATURATED PEGMATITES

All the undersaturated pegmatites are natrolite rich, with natrolite forming 10 to 40% of the pegmatite. Feldspars and amphibole are very coarse-grained, up to 20 cm long and 10 cm wide. A large natrolite pegmatite, almost 2 km long and 200 m wide, occurs along Highway 17, west of Little Pic River where it cuts the Western Gabbro. Typically, pegmatites are less than 10 m wide and less than 50 m long.

OVERSATURATED PEGMATITES

Oversaturated pegmatites typically occur in all the saturated to oversaturated rock types except the amphibole syenites. The pegmatites range from small irregular shaped patches, to well-developed dikes with sharp contacts, up to 4 m wide. Often the minerals will have grown from the margin inward, producing accicular amphiboles and feldspars up to 25 cm long and 5 cm wide. Some of the pegmatites have medium-grained patches which are mineralogically similar to the very coarse-grained part of the pegmatite. Although quartz is present in crystals up to 8 cm, it is not common in most syenite pegmatites. The abundance of feldspar and amphibole varies from massive feldspar to massive amphibole. The pegmatites hosting massive feldspar are the most common.

DIKES

Mafic dikes occur throughout the Coldwell Alkaline Complex. They were divided into lamprophyre dikes, aphanitic mafic dikes, and feldspar porphyritic mafic dikes.

Several types of lamprophyre dikes, ranging in size from a 10 cm to 3 m wide, were observed. The most common type is a fine-grained, black to green lamprophyre with calcite and local quartz ocelli which are concentrated within the centre of the dikes. Other types of lamprophyre were distinguished based on the presence of clinopyroxene or biotite phenocrysts. The lamprophyres are seen cutting all the rock units and appear to be less abundant east of Red Sucker Cove. The aphanitic mafic dikes, are black, highly fractured, 3 to 4 m wide, with sharp near vertical contacts. Feldspar porphyritic mafic dikes are reddish black, fine-grained, with medium-grained euhedral feldspar phenocrysts.

Diatremes.

Three diatremes in the Coldwell Alkaline Complex were examined. The largest of these is the Neys Diatreme which has been mapped by Balint (1977) and Sage (1982). This diatreme occurs on the west side of the Coldwell Peninsula. It is elliptical in shape and has sharp contacts with the host nepheline syenite. The breccia consists of rounded clasts of gabbro, syenite, nepheline syenite and amphibolite in communited matrix (Sage 1982).

Two smaller diatremes were discovered during mapping. The first is located on Highway 17 northwest of Neys Lake and the other occurs on the west side of Red Sucker Cove. Both diatremes are small (few 10s of m) and consist of angular, brecciated rock fragments in a hematized matrix.

ECONOMIC GEOLOGY

Base and Precious Metals.

Base and precious metal mineralization in the Eastern Gabbro is generally located near the contact of the gabbro with Archean metavolcanic rocks.

The Dunlop copper occurrence is exposed in the Eastern Gabbro along Highway 17. The occurrence is within massive, coarse gabbro which contains numerous xenoliths of Archean rocks and rheomorphic breccia. The main occurrence is located approximately 100 m from the contact of the Eastern Gabbro with Archean metavolcanic and metasedimentary rocks. The gabbro is coarse grained with plagioclase, clinopyroxene, olivine, magnetite, biotite and traces of apatite and up to 5% chalcopyrite.

The Marathon Cu-PGE occurrence of Fleck Resources Limited occurs within gabbro close to the east contact of the gabbro with Archean metavolcanic rocks. The Marathon Occurrence is located south of Bamoos Lake in the Two Duck Lake area. Mineralization is associated with chalcopyrite concentrations within coarse-grained pegmatitic Two Duck Lake Gabbro, which intrudes the layered Eastern Gabbro.

Cu-PGE mineralization is associated with chalcopyrite, cubanite, pyrrhotite, pentlandite and pyrite in the Two Duck Lake Gabbro (Good and Crocket 1990). PGEs are associated with the copper rich sulphides in the gabbro (Ohenstetter et al. 1989). Sulphides are commonly associated with hydrous minerals in the Two Duck gabbro, most commonly biotite is present but amphibole and chlorite are also common (Good and Crocket 1990). Sulphides are also commonly interstitial to fresh anhydrous silicates.

Layered Eastern Gabbro commonly has a mottled texture with apparent poikiloblasts of amphibole and/or pyroxene. This texture may indicate that the layered gabbros were metamorphosed and/or metasomatised by the later Two Duck Lake Gabbro.

The close association of mineralization with gabbro near the contact with Archean rocks suggests that mineralization may be related to assimilation of Archean sulphide-bearing rocks (Watkinson et al.1983).

A zone of chalcopyrite mineralization occurs on the east side of Detention Island at the contact between recrystallized quartz-amphibole syenite and nepheline syenite. The mineralization occurs in quartz veinlets and disseminations in syenite. A small adit has been dug along the sheared contact between the two rock types. No information regarding copper concentration could be found for this area.

Rare Metals

Pegmatites of the Coldwell Alkaline Complex were examined using a Scintrex Model BGS-1SL, Scintillation Counter. Based on the association of rare metals such as Nb, Ce, and Zr, with U and Th, the scintillation counter is a method of evaluating the potential of rocks for rare metal mineralization in the field. Both the undersaturated and saturated to oversaturated pegmatites had anomalous count rates; however, only pegmatites with count rates in excess of 10 times background were sampled. Saturated to oversaturated pegmatites, derived from the columnar-feldspar amphibole syenite near the roof pendant, accounted for most of the anomalies.

The two rare-metal occurrences, Port Munroe and Marathon Niobium occurrences, are hosted by pegmatitic syenite dikes intruding basalts of the roof pendant. The roof pendant may control the occurrence of rare metals. Results reported here support the observation of McLaughlin (1990), that the Port Munroe occurrence formed in a roof cupola.

The columnar-feldspar amphibole syenite consistently had twice the count rates of the porphyritic amphibole, recrystallized quartz amphibole, and ferroaugite syenites.

Two areas of anomalous count rates were discovered in the roof pendant zone. They occur along the Lake Superior Shore on the west side of Carden Cove, and the western side of Peninsula Hill. In Carden Cove, two amphibole-feldspar pegmatites less than 1 m wide, and three 10 to 15 cm wide fractures primarily filled with quartz, hosted within the diabasic rock of the roof pendant, had counts rates 20 times greater than background. In one pegmatite dike, a 30 cm wide section had 75 times the background count rate. On the west side of Peninsula Hill, a 50 m wide zone of north-trending columnar-feldspar amphibole syenite occurs in contact with the ferroaugite syenite. An amphibole-feldspar pegmatite within the columnar-feldspar amphibole, 1 m wide, had 20 times the background count rate of the column-feldspar amphibole syenite.

In addition to the rare metal occurrences associated with the columnar-feldspar amphibole syenite, a green feldspar pegmatite hosting fluorite, galena, quartz and graphic feldspar, occurring within the gabbro, may also be a target for rare metals. Two pegmatites, one on the east side of Highway 17 and hosted within the Eastern Gabbro near its contact with the Archean rocks, and the other on the west side of Highway 17 also hosted in the Eastern Gabbro but near its contact with the ferroaugite syenite, were discovered to have 50 and 150 counts per second above background, respectively. These types of pegmatites commonly occur in the Eastern Gabbro. The potential petrogenetic relationship, between the roof pendant and the columnar-feldspar amphibole syenite, may also be applied to the pegmatites in the Eastern Gabbro. The Eastern Gabbro could be a "cap" overlying evolved syenitic magmas, from which pegmatites intrude the overlying rock along zones of weakness.

Building Stone

Most exploration for building stone has occurred in black and red ferroaugite syenites exposed along the Canadian Pacific Railroad and Highway 17. Exploration on these prospects was discontinued because the syenites are too fractured and have numerous colour changes. New locations which are less fractured and do not have a significant colour changes, are being investigated north of Highway 17.

Industrial Minerals

The nepheline syenites within the Coldwell Alkaline Complex have been examined as a source for nepheline. The results indicated that the nepheline had too high an iron content. This may be due to zeolite and hematite crystallization in the nepheline syenites. Work will continue to attempt to locate nepheline syenite which does not contain zeolite minerals or hematite.

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19. Project Unit 91–11. A Geochemical Compilation of the Timiskaming Metavolcanic Rocks throughout the Superior Province, Ontario

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INTRODUCTION

This project is the first year of a two to three year investigation of the Timiskaming metavolcanic rocks in the Superior Province of Ontario. The objective of the investigation is to compile the available data on Timiskaming-type rocks in an annotated bibliography and to synthesize paleogeographic, geochemical and lithotectonic information that hopefully will enhance understanding of the mineralization environments associated with the Timiskaming-type rocks.

The term "Timiskaming Series" was first used by Miller (1911, p.648) who described rocks of the Cobalt area: "For the fragmental series, in which the cobalt silver veins characteristically occur, we propose to employ the name Cobalt Series, ...For the older, more disturbed conglomerate series, which outcrops at Kirk and Cross Lakes and in greater volume on Lake Temiskaming, outcrops also being known a considerable distance south of Cobalt and 90 miles to the northwest at Porcupine the name Temiskaming will be used". No volcanic rocks are associated with these rocks as so defined and the rocks at Cobalt are no longer assigned to the Timiskaming (Ontario Geological Survey 1991).

As Timiskaming-type sequences are now understood, Blackburn et al. (in press) have found sequences in the Superior Province that are comprised of fluvatile sequences and interlayered calc-alkalic to alkalic metavolcanics. The sequences unconformably overlie older greenstone sequences and were formed later than a D_1 deformation event but prior to a subsequent D_2 deformation episode occurring after 2.7 Ga (Stott 1985; Corfu and Stott 1986; Corfu et al. 1991). The sequences are thus generally younger than 2.7 Ga and the depositional environment may represent: 1) "pull-apart" basins formed by strike-slip faulting with subsequent deposition in dilatational jogs (Thurston and Chivers 1990); 2) basins formed by late rifting; 3) basins formed during late-stage arc volcanism (Corfu et al. 1991); or 4) the rocks may occur as molasse sequences (G.M. Stott, Ontario Geological Survey, personal communication, 1990). The type area for the Timiskaming-type sequence sediments and volcanics, has by concensus become the Kirkland Lake, Ontario, area following numerous mapping projects and detailed studies.

Timiskaming-type metavolcanics have been described from many areas of the Superior Province in Ontario, for example the Shebandowan area (Shegelski 1980; Carter 1987, 1988, 1989, 1990a, 1990b). Carter (1987) and Thurston and Chivers (1990) describe the lithostratigraphy of the Timiskaming-type sequences and provide references to the older literature on those rocks.

In this summary the author reports on a compilation of geochemical data from the literature and on field investigations in specific areas of the Superior Province.

GEOCHEMISTRY OF TIMISKAMING-TYPE METAVOLCANICS

Data for this compilation were obtained from Todd (1928), Hopkins (1925a, 1925b), Thompson (1943), Cooke and Moorhouse (1969), Goodwin (1979), Shegelski (1980), Jensen and Langford (1985), Ujike (1985), Barron et al. (1989), Ben Othman et al. (1990), and Carter (1990a, 1990b) and are listed in Tables 1, 2 and 3.

Major elements

The Timiskaming-type rocks have been classified into calc-alkalic and alkalic rocks based on the Peacock variation diagram (Peacock 1931), the AFM diagram (Wager and Deer 1939; Irvine and Baragar 1971), Niggli alk-si values (Barth 1952), the Ti-Zr-Y diagram of Pearce and Cann (1973) and the K_2O vs. SiO_2 diagram of Mackenzie and Chappell (1972).

Table 1 shows the ranges of the anhydrous values of the major elements of the alkalic and calc-alkalic rocks. In Table 2, analyses of a sodic alkalic suite (from Jensen and Langford 1985) are shown, which indicate consistently higher TiO_2 values than those of Table 1. On the basis of silica content, all the rocks of Table 1 and Table 2 range from basic to intermediate in the IUGS classification (Le Maitre 1989). Timiskaming-type calc-alkalic rocks range from basalt to rhyolite; alkalic rocks, which include shoshonitic rocks, range from trachybasalt to trachyte, and from tephrite to tephriphonolite (*see* Figure 1).

Table 1. Ranges of anhydrous major element oxide concentrations in weight percent of Timiskaming-type alkalic and calc-alkalic rocks, Superior Province, Ontario. See text for sources of data.

	ALKALIC ROCKS		CALC-ALKALIC ROCKS	
	Kirkland Lake	**Thunder Bay** (Shebandowan-Kaministiquia Area)	**Kirkland Lake**	**Thunder Bay** (Shebandowan-Kaministiquia Area)
Sio_2 (wt %)	48.70–61.22	51.60–69.45	52.97–57.10	50.28–68.48
TiO_2	0.22–1.52	0.31–0.95	0.69–0.84	0.42–1.09
Al_2O_3	13.18–22.55	13.87–21.12	17.47–21.67	15.21–19.36
Fe_2O_3	0.77–7.31	1.57–4.31	0.41–3.22	0.64–4.44
FeO	1.49–8.43	0.41–7.41	5.53–7.26	1.54–9.34
FeO(T)	5.20–9.62	n.d.+	n.d.+	n.d.+
MnO	0.01–0.36	0.04–0.19	0.09–0.19	0.04–0.18
MgO	0.76–7.85	1.02–7.06	5.98–7.13	1.23–9.31
CaO	1.02–10.72	2.64–10.13	0.95–7.14	1.50–9.49
Na_2O	0.12–6.85	2.67–5.51	3.66–4.73	1.35–5.99
K_2O	0.30–12.14	2.17–5.51	0.02–2.89	0.52–1.97
P_2O_5	0.12–1.32	0.09–0.40	0.13–0.41	0.05–0.36
Number of samples	**149**	**20**	**3**	**10**

**FeO(T): Total iron reported as FeO*
+n.d.: not determined

Table 2. Chemical composition of Timiskaming-type alkalic metavolcanic rocks, Kirkland Lake Area (L.S. Jensen and F.F. Langford 1985, Table 2).

Analyses No.	**1**	**2**	**3**	**4**
SiO_2 (wt.%)	43.00	44.80	47.10	53.90
TiO_2	3.24	3.23	3.27	2.72
Al_2O_3	11.80	12.20	13.20	13.50
Fe_2O_3 (T)#	14.20	12.80	14.10	13.60
MnO	0.24	0.27	0.21	0.20
MgO	4.83	4.53	3.86	2.94
CaO	10.00	10.30	8.00	6.03
Na_2O	5.18	5.50	6.10	6.69
K_2O	1.91	0.75	0.97	0.34
P_2O_5	n.d.	n.d.+	n.d	n.d.
L.O.I./	5.27	6.25	4.40	1.45
Total	**100.1**	**100.6**	**100.2**	**100.4**

1. Nephelinite; greenish-grey, fragmental, magnetic (Na-alk bas. ser.)*
2. Nephelinite; grey, aphanitic, magnetic (Na-alk.bas ser.)*
3. Nephelinite; grey. 0.5 mm grained, massive, magnetic (Na-alk.bas.ser.)*
4. Mugearite; dark, bluish-grey, massive, magnetic (Na-alk-bas ser.)*

** sodic alkalic-basalt series*
+ n.d. not determined.
#Fe_2O_3(T): Total iron reported as Fe_2O_3
/L.O.I.: Loss on ignition.

Table 3. Ranges of trace element concentrations of Timiskaming-type alkalic and calc-alkalic rocks.

	ALKALIC ROCKS	CALC-ALKALIC ROCKS			
Element	Kirkland Lake	Thunder Bay (Shebandowan-Kaministiqiua Area)	Birch Lake (Springpole Lake Area)	Kirkland Lake	Thunder Bay (Shebandowan-Kaministiqiua Area)
Sn (ppm)	0.17-3.3	133-193	n.d.	n.d.	n.d.
Sb	2.3-9.3	n.d.	n.d.	n.d.	n.d.
Cs	2-26.8	n.d.	n.d.	n.d.	n.d.
Rb	72-340	38-375	190-375	n.d.	9-55
Ba	167-7070	787-4900	2096-2726	179-1612	100-758
Sr	455-2610	496-1359	496-532	n.d.	75-1220
Nb	9-24	<5-23	n.d.	n.d.	<5-12
Zr	113-499	60-315	181-315	n.d.	5-180
Hf	4.3-17	n.d.	n.d.	n.d.	n.d.
Ta	0.3-0.7	n.d.	n.d.	n.d.	n.d.
Pb	7.9-80	<100-20	n.d.	n.d.	<10-11
Th	13.7-91	n.d.	n.d.	n.d.	n.d.
U	1-190	n.d.	n.d.	n.d.	n.d.
La	93.4-274	52-89	n.d.	n.d.	n.d.
Ce	167.8-520	47-73	n.d.	n.d.	n.d.
Pr	25-63	n.d.	n.d.	n.d.	n.d.
Nd	68.1-228	n.d.	n.d.	n.d.	n.d.
Sm	11.9-38	n.d.	n.d.	n.d.	n.d.
Eu	2.98-13.9	n.d.	n.d.	n.d.	n.d.
Gd	n.d.	n.d.	n.d.	n.d.	n.d.
Tb	0.86-2.31	n.d.	n.d.	n.d.	n.d.
Dy	n.d.	n.d.	n.d.	n.d.	n.d.
Ho	0.98-5.4	n.d.	n.d.	n.d.	n.d.
Er	3.1-12.3	n.d.	n.d.	n.d.	n.d.
Tm	n.d.	n.d.	n.d.	n.d.	n.d.
Yb	1.40-9.6	n.d.	n.d.	n.d.	n.d.
Lu	0.16-1.4	n.d.	n.d.	n.d.	n.d.
Y	17-107	8-25	n.d.	n.d.	6-20
V	145-470	70-230	n.d.	n.d.	7-245
Cr	<5-833	2-4750	n.d.	n.d.	16-465
Ni	1-458	41-780	n.d.	n.d.	27-112
Co	7-49	11-350	n.d.	n.d.	14-75
Sc	3.4-21.4	5-25	n.d.	n.d.	7-35
Cu	30-272	7-1120	n.d.	n.d.	14-124
Zn	13.8-161	37-158	n.d.	n.d.	47-173
Ag	0.15-0.17	<2	n.d.	n.d.	<2
Mo	n.d.	<10	n.d.	n.d.	<10
Ga	1.5-16	16	n.d.	n.d.	16-26
Be	n.d.	2	n.d.	n.d.	1-2
Li	n.d.	14-140	n.d.	n.d.	11-26
No. of samples	134	4	2	3	39

In the literature the alkalic rocks of Timiskaming-type are commonly referred to as trachytes and mafic trachyte but it can be seen (*see* Figure 1) that only a very small proportion actually occurs in the trachyte-quartz trachyte field. The Kirkland Lake rocks were originally called soda trachyte by Cook (1922, p.24) but no mode or chemical analyses were given. Subsequent use of the term trachyte for these rocks probably stemmed from this original usage and continued even when chemical analyses were available indicating that these rocks really were not trachytes. Table 2 shows a set of sodic alkalic rocks with a higher TiO_2 content than those of Table 1 which represent a predominantly potassic series. These higher TiO_2 values are characteristic of continental rift alkalic series (Kesson and Smith 1972; Wilson 1989). Rocks of this kind are not known to exist in other Timiskaming-type sequences of Ontario.

Cooke and Moorhouse (1969), Ujike (1985) and Ben Othman et al. (1990) stress the altered nature of the rocks they investigated but did not screen the analyses to eliminate strongly altered rocks. The CO_2 content of all alkalic rocks listed here commonly exceeds the limits established by Le Maitre (1989) for unaltered volcanic rocks (less than 0.5% CO_2 and less than 2.00% H_2O+). Thus the classification of some of these rocks could be in error if the constituents SiO_2, Na_2O and K_2O used for classification were mobile during alteration.

Trace elements

Table 3 shows trace-element data for Timiskaming-type alkalic and calc-alkalic rocks. The data are very sparse, however, the high values for Rb, Ba and Sr and light rare-earth elements in the alkalic rocks are characteristic of shoshonitic rocks in convergent subduction-related arc/active margin Phanerozoic plate tectonic environments (Morrison 1980; Wilson 1989). The lower values for Rb, Ba and Sr in the calc-alkalic rocks as compared with the alkalic rocks help to confirm the division of the Timiskaming-type rocks into alkalic and calc-alkalic rocks. Alkalic rocks resembling Timiskaming-type rocks occur in Phanerozoic arc systems and in four tectonic settings: arc rifting, arc-continent collision, near arc termini and above deep Wadati-Beni zones (Box and Flower 1989).

FIELD INVESTIGATIONS

In 1991, field investigations were carried out at North Spirit Lake, at Springpole Lake (Birch Lake Area), Kirkland Lake, Matachewan and Shining Tree. Samples were collected from most of these areas for further geochemical study.

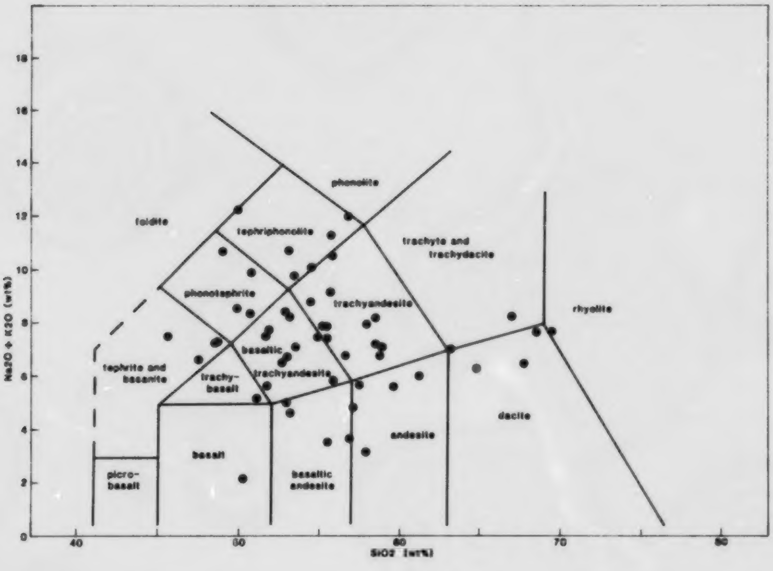

Figure 1. $Na_2O + K_2O$ versus SiO_2 plot (anhydrous values) of Timiskaming-type calc-alkalic and alkalic rocks, Superior Province, Ontario. Diagram after Le Maitre, 1989, p.28–29.

On North Spirit Lake (at Pontoon Bay, Bijou Point and South Bay) samples were collected from shore-line outcrops of felsic to intermediate metavolcanic rocks interlayered with conglomerates (unit 2 of Wood 1977). In this area, Smith and Longstaffe (1974) reported the occurrence of shoshonitic rocks on the basis of chemical analyses. The rocks so described by Smith and Longstaffe (1974) appear, to the author, to be similar to tholeiitic and calc-alkalic mafic to intermediate rocks, on the basis of lithological characteristics. Thurston and Chivers (1990, p.22-28 and Figure 1 p.23) classify the underlying units as a quartz arenite and carbonate-bearing platform sequence. Based on field work alone they do not appear to represent a Timiskaming-type sequence.

At Springpole Lake, in the Birch Lake Area, grey-weathering, greyish-white feldspar-phyric rocks showing trachytic texture were observed associated with a white-weathering, feldspar-phyric syenitic rock. These trachytic rocks were not observed interlayered with Timiskaming-type conglomerates reported elsewhere. The distribution of these rocks is shown by Barron et al. (1989, Figure 331.2). K.M. Barron (graduate student, University of Western Ontario, personal communication 1991) showed the author red-weathering trachytic, feldspar-phyric volcanic rocks from Springpole Lake which are similar in appearance to Timiskaming-type alkalic metavolcanic rocks elsewhere. These rocks, however, were not seen in the field by the writer. Thurston and Chivers (1990, p.22-28 and Figure 2.3) classify these rocks of the Birch Lake area as belonging to a pull-apart basin sequence of less than 2.7 Ga, i.e. a Timiskaming-type sequence.

At Kirkland Lake the type alkalic volcanic rocks of the Timiskaming-type suite were examined and samples collected from flows in Hislop, Lebel, Teck, and Grenfell townships. These rocks are similar in appearance to rocks of the Shebandowan-Kaministiquia (Thunder Bay) and Shining Tree areas (Carter 1990a, 1990b, and 1977, 1983, respectively).

In the Matachewan area reported outcrops of possible alkalic metavolcanic rocks (R. Junilla, D. Conrod, Geologists, formerly of the Ontario Geological Survey, personal communications, 1988) of Timiskaming-type were examined in Yarrow Township, but field examination suggested these rocks were not alkalic metavolcanic rocks based on field lithologic examination. In Powell Township, just west of Matachewan, fine-grained, red, felsic rocks resembling Timiskaming-type rocks were examined by the author. They represent a fine-grained facies of syenitic rocks as mapped by Lovell (1967). Near the occurrence of these syenitic rocks, float of alkalic trachytic rocks were examined by the author at the Young-Davidson mine dump (Property 12 on Map 2110, Lovell 1967). The existence of these rocks at the mine were reported by R. Junilla and D. Conrod (personal communications, 1988).

In Shining Tree alkalic rocks previously mapped (Carter 1977, 1983) were re-sampled to supplement samples previously collected. Comparison of these rocks with those of the type area of Kirkland Lake on the basis of field, petrographic and chemical characteristics showed a very close resemblance of the two suites of rocks.

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20. Project Unit 89–72. Stratigraphy and Sedimentation of the Metasedimentary Rocks of the Grenville Supergroup in Southeastern Ontario

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INTRODUCTION

Since the middle of the 19th century, the carbonate rocks of the Grenville Province in Ontario have contributed to the mineral production of Ontario. Iron was one of the earliest metals produced from marble-hosted deposits of the Grenville. In addition graphite, copper, zinc, mica, marble for building stone and marble for lime production has come from Grenville marbles (Hewitt and Vos 1972; Storey and Vos 1981 a, 1981b; Carter 1984; Malczak et al. 1985).

Mineral production from the clastic metasedimentary rocks has consisted mainly of pyrite for production of sulphur and/or sulphuric acid from strata-bound, sedimentary-hosted lenses of pyrite such as those of the Blakely and Canadian Sulphur Ore Company mines in the field area, the Bannockburn Pyrite Mine in northern Madoc Township, and the Hungerford Mine and Ontario Sulphur Mine northeast of Tweed, Hungerford Township (Malczak et al. 1985).

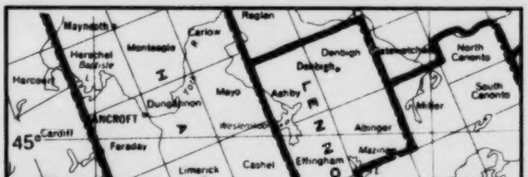
Maynooth
Herschel
Monteagle
Carlow
Raglan
Denbigh
North Canonto
South Canonto
Harcourt
BANCROFT
Dungannon
Mayo
Ashby
Abinger
45°
Cardiff
Faraday
Limerick
Cashel
Effingham
Clarendon
Eels
Chandos
Wollaston
Barrie
Anglesea
Big Gull Lake
Olden
Grimsthorpe
Tudor
Kennebec
Burleigh
Methuen
Lake
Kaladar
Elzevir
Madoc
Sheffield
Belmont
Marmora
Tweed
Dummer
Havelock
Hungerford
Douro
Rawdon
Huntingdon
Asphodel
Seymour
Tyendinaga
Campbellford
Stirling
Thurlow
Percy
Sidney
BELLEVILLE
Frankford
Murray
Trent Canal
Deseronto
NORTHUMBERLAND
TRENTON
Quinte
Cramahe
Brighton
Haldimand
Hamilton
Colborne
Ameliasburgh
Sophiasburgh
Hallowell
N. Marysburgh
44°
Cobourg
PRINCE EDWARD
Presqu'ile Point
Hillier
Wellington
S. Marysburgh
Athol
LAKE ONTARIO
77°
20
0
40
Scale of Kilometres

Figure 1. Location map of study area, scale 1:1 584 000.

Several other sulphide-bearing prospects and occurrences are also hosted by clastic and carbonate metasediments, frequently in association with volcanic rocks (Carter 1984; Malczak et al. 1985).

The author started a detailed (1:5000) mapping program in the metasedimentary rocks of the Madoc–Havelock area in order: 1) to determine if stratigraphic and sedimentation studies are possible in these metamorphosed and deformed rocks; 2) to get a better understanding of the setting of the known mineralization; and 3) to provide possible leads to additional mineralization (Meyn 1988, 1989, 1990).

In 1991 detailed mapping (1:5000) was carried out in Madoc Township in the vicinity of Rimington and in Belmont Township in the area northeast of Belmont Lake (Figure 1).

GENERAL GEOLOGY

Little detailed work has been done on sedimentary rocks, in general, or the marbles, in particular, in the Central Metasedimentary Belt of the Grenville Province in Ontario. Among the earliest workers were Adams and Barlow (1910) who recognized amphibolite layers in marble as metasediments and Miller and Knight (1914) who published a synthesis of the Precambrian geology of southeastern Ontario. A more general overview of the local and regional metasedimentary geology is given by Lumbers (1964) and Hewitt (1968).

This summer's field work in Madoc Township was fill-in mapping along strike between previously mapped areas. The rock types present are the same as encountered in previous years. The predominant lithology was thinly laminated, grey calcitic marble. In certain local small patches adjacent to zones of structural dislocation, this marble may be white and massive. In the marble a small amount of thin interbeds of arenaceous wacke or intermediate to felsic tuff are common. Because of their more siliceous composition these beds are more resistant to weathering and thus form raised ridges on the outcrop. The author encountered one occurrence of thinly laminated dolomitic marble interbedded with calcitic marble.

The field work in Belmont Township extended the mapping from Belmont Lake to the northeast. Most of Belmont Lake is underlain by the siliciclastic metasediments of the Belmont Lake Formation. These sediments form a series of fining-upward cycles. The tops of the cycles are characterized by dolomitic algal laminates. Northeastward from the shore of the lake, the amount of calcitic marble in the section increases. The exposed rock types are a mixture of calcitic marble, massive beige weathering dolomite, minor conglomerate, minor sandstone and mudstone.

Conglomerate was only seen in one unit. Here the conglomerate is polymictic but the predominant pebble lithology is pink rhyolite. The sandstone is medium-grained, grey weathering quartz arenite. The mudstone is a very fine-grained, dense black rock. Carbonate and pyrite are common accessory minerals. From hand specimen it is not immediately obvious if this is primary or secondary mineralization.

The beige dolomite contains considerable quartz (chert) lenses that may be the result of silicification of algal laminates with subsequent recrystallization and structural disruption into lenses from original fairly continuous algal mats. Much less common are algal laminates sufficiently well preserved to be identifiable. There is one small area of dolomite that features "zebra-pattern" cement in and around fragments of algal mats. This feature is rather difficult to identify in the massive, weathered, moss-covered outcrop under a continuous tree canopy. It is best seen in polished hand specimen.

At Belmont Lake, the lower part of the sequence contains several occurrences of volcanic rocks and several small diabase dikes and sills. The amount of volcanic rock seen is much less in the northeast, but some small mafic and felsic dikes are present.

Contact metamorphic effects associated with the Cordova Gabbro are quite pronounced near it (deKemp 1984) and they show an irregular pattern probably reflecting irregular subsurface distribution of the gabbro. For the purposes of this program the gabbro was mapped where encountered near its contact with the country rocks, but was not mapped/studied any further.

STRUCTURAL GEOLOGY

Preliminary examination of the map suggests that structural relationships in the area northeast of Belmont Lake are quite complex. A general overall north strike is maintained but the area seems to be broken up into many small individual fault blocks as indicated by changes in strike and lithology. Graded bedding and cross-bedding indicate tops are to the east. The base of the sedimentary sequence, which is in contact with the metavolcanic rocks to the west, is a north-trending fault. The contact with the felsic metavolcanic rocks to the north is characterized by a rotation of strike into an east direction. This seems to be a fault also.

ECONOMIC GEOLOGY

In the past, the mapped area of Madoc Township has seen production of pyrite, gold and stone for roofing granules. Present mineral production is confined to marble-chip production by Stoklosar Marble Quarries Limited from various small quarries in Madoc Township and aggregate production from a quarry in Ordovician limestone in Lot 14, Concession VII, Madoc Township (just west of the Cooper road). Sand and gravel for local needs is produced from local borrow pits. Although much of the area is covered with Pleistocene deposits, there are few good sand or gravel deposits in the area.

Mineral production from the metasedimentary rocks of Belmont Township was predominantly iron from contact skarn deposits in carbonate metasediments associated with several different intrusions. Bartlett et al. (1985) describe these skarns as follows: "The skarns are dense, fine-grained rocks composed mainly of andradite garnet, green clinopyroxene, amphibole, epidote, magnetite, pyrite, pyrrhotite and carbonate; chalcopyrite is a minor constituent." In the area mapped, the prominent iron deposit is that of the Belmont/Ledyard iron mine in Lot 19, Concession I, Belmont Township. The mine workings consist of two open pits in a skarn zone about 200 m long by 30 m wide and a shaft reported to be 260 feet (about 80 m) deep. This mine saw production in 1899, 1900 and again from 1911–1913. A total of about 8500 tons of ore grading about 50% iron was produced from this mine. The property was last examined in 1970. At that time nearly 1 million long tons of magnetite-bearing rock averaging 31.47% magnetic iron was outlined. (Ministry of Northern Development and Mines files, Bancroft).

Also associated with the contact-metamorphic halo of the Cordova Gabbro is the development of talc mineralization in carbonate metasediments (LeBaron and van Haaften 1989). There is a shallow pit about 40 m long, 3 m wide and 2 m deep on this mineralization but there is little talc exposed in it. There is no reported production from this occurrence.

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21. Development of a Pen-Based Computer System for the On-Site Recording of Geological Field Notes

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INTRODUCTION

During 1991, the Precambrian Geology Section of the Ontario Geological Survey initiated a pilot project to test a computer-based procedure for the digital acquisition of geological information directly in the field. The project was designed to take advantage of the recent introduction of the pen-based computer—a lightweight, handheld device which utilizes a tethered pen rather than a keyboard for data input. The purpose of the pilot project is essentially two-fold; firstly, to determine whether a pen-based computer can withstand the considerable abuse likely to occur during normal field operations; and secondly, to design and test a custom software application written for the device to permit the rapid and accurate collection of geological data. This contribution discusses the rationale behind the pen-based computer project, followed by some of the characteristics of the hardware. It then examines the software designed for capturing and structuring the data, and finally, discusses some of the benefits, perceived and tangible, which may result.

PROJECT RATIONALE

Over the past several years, the Precambrian Geology Section has begun to take advantage of available computer technology for the storage and retrieval of geological information. The OGS FIELDLOG system, developed recently for the storage of field data in digital format and the production of digital geological maps from this data, represents our primary initiative in this direction (Brodaric and Fyon 1989a, 1989b, 1990). However, the actual process of transferring information into FIELDLOG databases still relies upon two separate manual processes. First, geological information is recorded in the field by hand, and second, that information is later reinterpreted to fit the database format in use, and keyed into a base computer. Thus, a duplication of effort is required in the capture of information, and the integrity of that data may be compromised depending upon who is interpreting and transferring the information into digital format. Ideally, data capture should occur only once, directly at source where information is originally observed and interpreted, and by the individual making the observations. This latter approach should maximize both the integrity of data captured, and the complete recording of available information.

One of the traditional problems with hand-written field notes is that they tend to be of limited use to anyone but the original field geologist who recorded them. This may occur as a result of variations in handwriting style, or user-specific codes and abbreviations used, or perhaps the type and amount of data recorded. A primary objective of the present project is to make original field observations taken by geologists usable by anyone, at any stage of a field project, while at the same time retaining the flexibility required to include the full range of geologist's mapping styles and project designs. Thus, the pen-based computer was seen as a potential tool to systematize the collection of field data for all mapping geologists, and promote the transfer and sharing of all field observations in a standardized format, without requiring major adjustments by the geologists involved. The level of complexity at which the pen-based computer requires information at geological stations is dependant upon the level of information the geologist wishes to provide, and relatively little computer experience is required to operate the unit or the software.

THE PEN-BASED COMPUTER

The unit being tested is a fully functional 8086-10 Mhz pen-based computer which uses a tethered magnetic pen to input information or commands rather than a traditional keyboard. It contains 1 Mb on-board RAM and 2 Mb of mass storage space (in the form of RAM cards—there are no movable disk drives). The unit is small in size, measuring 31.4 cm. x 23.5 cm. x 3.6 cm. (slightly larger than an airphoto clipboard) and weighing 2 kg with the battery. It packs snugly into a padded protective case which can easily be carried in a day pack. The durable screen surface almost completely covers the long dimension of the computer, maximizing the area in which program commands, icons and data can be displayed. The computer has an extended battery life of eight hours, and can be put into dormant mode between data recording sessions, thus preserving battery life and usable hours. It runs from a standard DOS operating platform, and contains several communications input/output ports for data transfer or printing.

Commands and data may be entered into the device through either of two distinct methods. The pen may be used to "touch" icon-like buttons or display areas, from which a scrolling list of possible entries will be displayed. The desired entry may then be "touched" or a digital image of a keyboard may be brought up, from which the response is "touch-typed". The computer also possesses "handprinting recognition" software, such that responses may be directly "written" in using the pen. However, this feature is not suitable for long responses, and is best used for short one or two character entries. In designing the software to accept geological information, the suitability of the two methods of data entry was carefully assessed and utilized accordingly, in order to achieve an application that was both quick to use and accurate.

SOFTWARE DESIGN AND CONSTRUCTION

In designing a custom software application to take full advantage of the features of the hardware, due regard for the constraints imposed by the existing FIELDLOG field data storage and mapping software was considered. However, a logical flow to the information to be input was also identified as a priority towards tailoring the application to typical field note recording techniques. As result, the basic modular structure of FIELDLOG has been retained, in which relational databases of information are linked to one another through a key field, the station number.

A geological station is defined as a place in geographic space in which one or more lithologies are observed. Therefore, the station number is the key field to which all other observations are related. Once a lithology is defined at a station, structural and mineralogical attributes of that lithology may or may not be recorded, depending upon their significance to the mapping project. Also, at the station, a sample or samples may or may not be taken, as is also the case with photographs. To summarize, a station is defined by one or more lithologies, for each of which structural measurements or mineralogical features may be recorded if significant. Several samples and photographs may be taken at the station. The relationships between these subdivisions of geological data are depicted in Figure 1.

The software, termed "FIELDMAPPER" (Cherer and Troop 1991), is strictly for textual and numeric data collection, and presents the user with six different data entry screens, one for each of the relational data groups discussed above. The datasets created from these entry screens are named STATION, SAMPLE, PHOTO, LITHOLOGY, STRUCTURE, and MINERALOGY, and these are downloaded into FIELDLOG DBF modules of the same names. Thus, a standardized overall database design will be adopted for all projects utilizing FIELDLOG. At present, the user creates his own modular design in FIELDLOG. This flexibility is useful for non-conforming usages, and occassionally desirable, but unfortunately does not allow for the merging of geological data from different projects, if a different database design has been used. All data recorded through FIELDMAPPER and subsequently downloaded in FIELDLOG will be fully integratable.

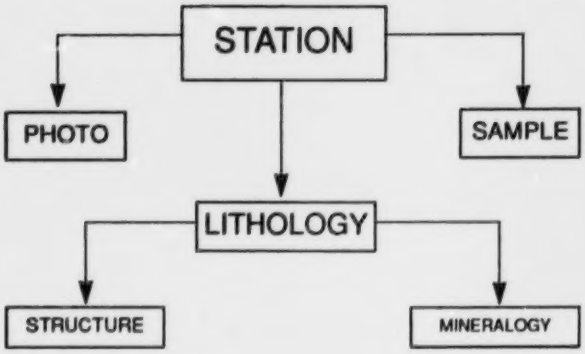

Figure 1. Information hierarchy.

Upon startup, FIELDMAPPER displays the stations with information currently stored in the device. Adding a new station by touching the appropriate prompt with the tethered pen brings up the first screen, the STATION module. The station number is automatically defaulted to an increment of one over the previously recorded station. Other data such as airphoto number, coordinates, lithology legend code, and date may be filled in at this time, and some fields have default values. Once the STATION number is created, a LITHOLOGY can be added, or a SAMPLE or PHOTO taken can be recorded, again by touching the appropriate prompts. Once a LITHOLOGY has been added, the user may record specific STRUCTURE or MINERALOGY features as required. Logically, there is a minimum number of fields that must be filled on each screen to save the data (ie. LITHOLOGY must be given a rock name), but not all the fields present in a module need be filled. The most common method of data entry is by presenting drop down pick lists of possible responses, from which the applicable value is chosen. The contents of these pick lists can be modified to suit individual projects. Some fields, such as strike/dip and trend/plunge in the STRUCTURE module require handwritten numeric data entry. Finally, each module has a NOTES field for free form notes, to accomodate instances where the geologist has made observations which cannot be simply recorded using the available data fields. Figure 1 shows the entire data structure of the FIELDMAPPER application, and detailed data descriptions for each module (*see* Figures 2 to 7) are shown, witn example pick lists where appropriate. It should be noted that a review of the contents of the pick lists will be undertaken shortly in order to establish a standardized data dictionary of geological terminology for use on mapping projects.

FIELDMAPPER also has Print and Transfer commands, which permit the user to produce printed station by station output records, or to download accumulated station data into existing FIELDLOG databases for further analysis or provisional map construction at the end of a traverse. The printed station records form a permanent hard copy record of field observations similar to traditional handwritten notes, thus

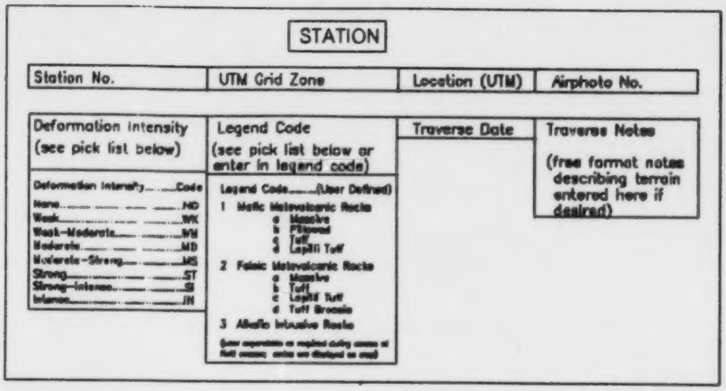
STATION
Station No.
UTM Grid Zone
Location (UTM)
Airphoto No.
Deformation Intensity (see pick list below)
Deformation Intensity.......Code
None.......ND
Weak.......WK
Weak-Moderate.......WM
Moderate.......MD
Moderate-Strong.......MS
Strong.......ST
Strong-Intense.......SI
Intense.......IN
Legend Code (see pick list below or enter in legend code)
Legend Code.......(User Defined)
1 Mafic Metavolcanic Rocks
a Massive
b Pillowed
c Tuff
d Lapilli Tuff
2 Felsic Metavolcanic Rocks
a Massive
b Tuff
c Lapilli Tuff
d Tuff Breccia
3 Alkalic Intrusive Rocks
Traverse Date
Traverse Notes
(free format notes describing terrain entered here if desired)

Figure 2: Station module

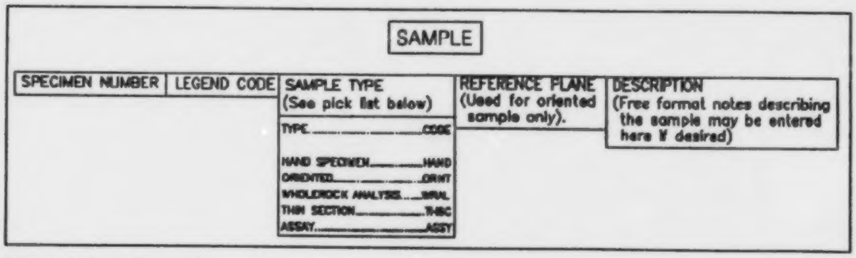
SAMPLE
SPECIMEN NUMBER
LEGEND CODE
SAMPLE TYPE (See pick list below)
TYPE.......CODE
HAND SPECIMEN.......HAND
ORIENTED.......ORNT
WHOLEROCK ANALYSIS.......WRAL
THIN SECTION.......THSC
ASSAY.......ASSY
REFERENCE PLANE (Used for oriented sample only).
DESCRIPTION (Free format notes describing the sample may be entered here if desired)

Figure 3: Sample module

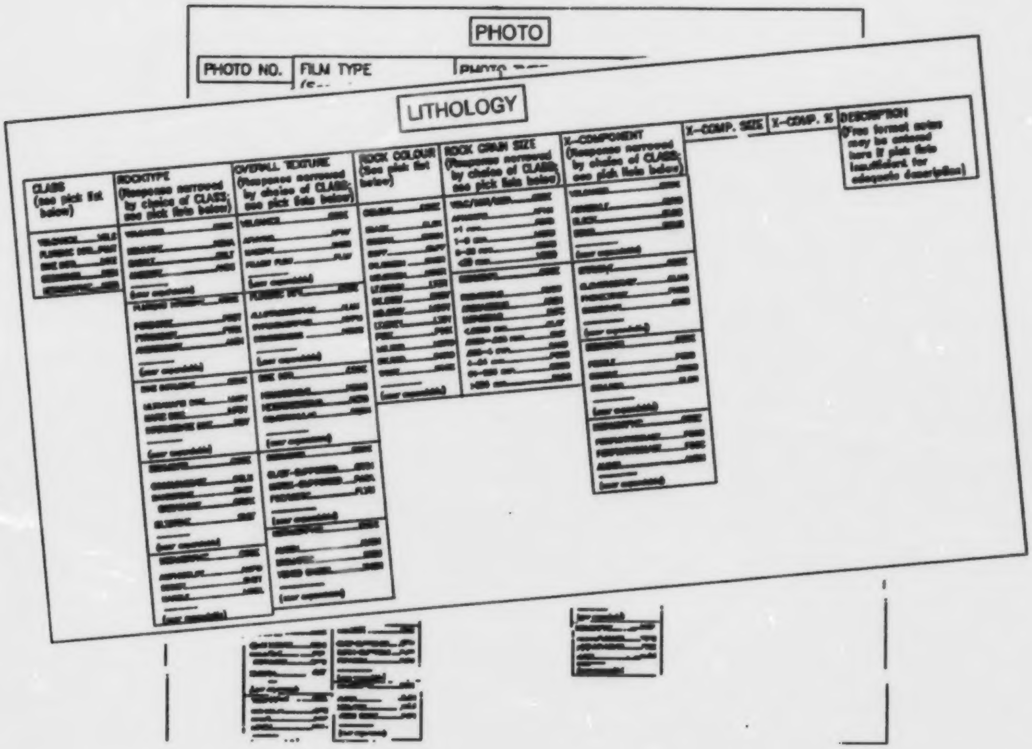
PHOTO
PHOTO NO.
FILM TYPE
LITHOLOGY
CLASS (see pick list below)
ROCKTYPE (Response narrowed by choice of CLASS; see pick lists below)
OVERALL TEXTURE (Response narrowed by choice of CLASS; see pick lists below)
ROCK COLOUR (See pick list below)
ROCK GRAIN SIZE (Response narrowed by choice of CLASS; see pick lists below)
X-COMPONENT (Response narrowed by choice of CLASS; see pick lists below)
X-COMP. SIZE
X-COMP. %
DESCRIPTION (Free format notes may be entered here if pick lists insufficient for adequate description)

Figure 5: Lithology module

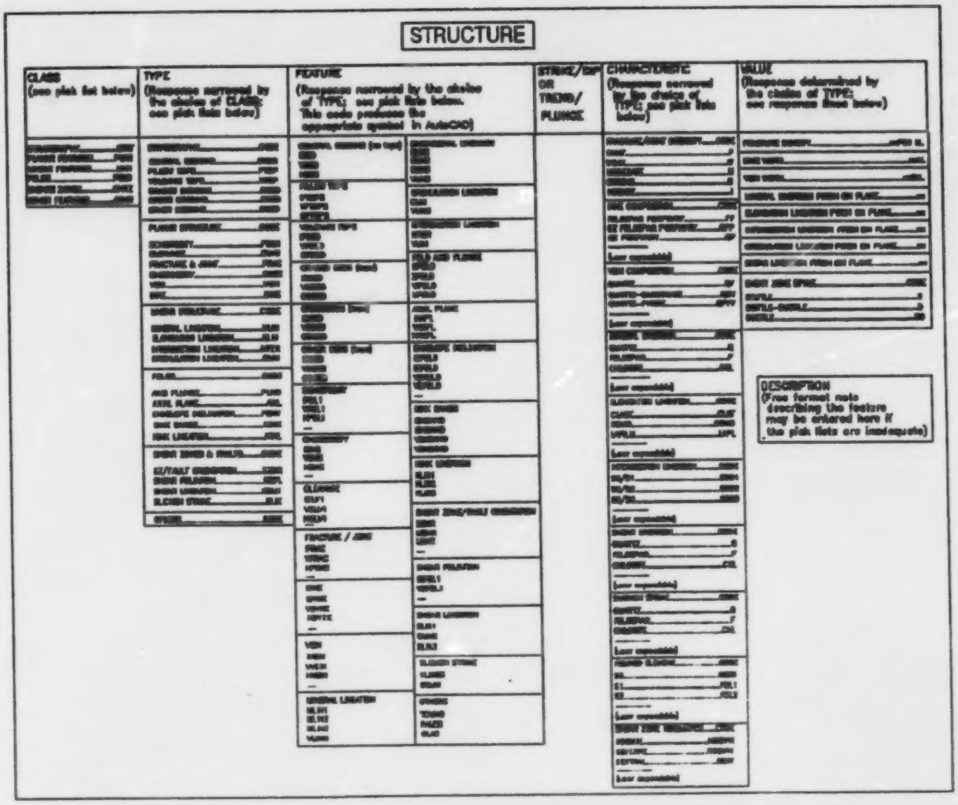
STRUCTURE
CLASS
TYPE
FEATURE
STRIKE/DIP OR TREND/ PLUNGE
CHARACTERISTIC
VALUE
DESCRIPTION
(Free format note describing the feature may be entered here if the pick lists are inadequate)

Figure 6: Structure module

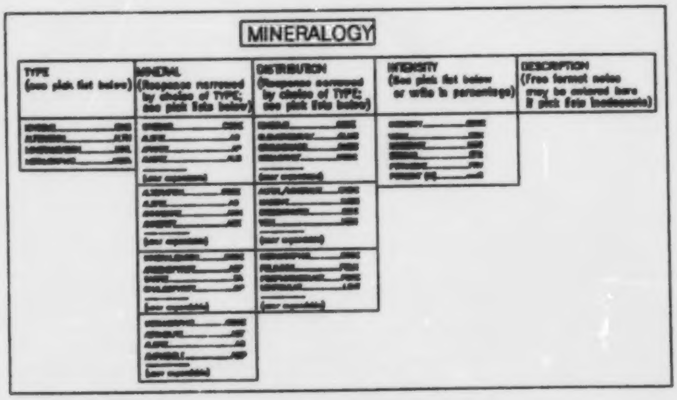
MINERALOGY
TYPE
MINERAL
DISTRIBUTION
INTENSITY
DESCRIPTION

Figure 7: Mineralogy module an upright synform-antiform pair

providing one form of information backup. Furthermore, daily traverse data files may be saved to the base computer in their original form (ie. pre-conversion to FIELDLOG DBF files), to provide a secondary digital backup, should the FIELDLOG databases ever become irrevocably damaged.

In order to develop a professional application in the shortest possible time span, an outside consulting firm with extensive experience in programming pen-based applications was selected. A prototyping methodology to systems development was selected, utilizing a proprietary development environment, to ensure maximum Precambrian Section involvement and maintain a user's perspective on the application. Using a modular approach, FIELDMAPPER was created within a three week time period.

CONCLUSIONS

At the time of writing, field testing of the computer and custom application software had not been completed. However, early feedback from the testing geologist has been favourable with respect to the overall appearance and functioning of the prototype application. While the need for some modifications to the software will undoubtedly become evident as testing progresses, the program does not appear to be a barrier to the rigourous testing of the handheld unit under field mapping conditions.

In summary, four principal benefits may accrue to the Precambrian Geology Section from the successful completion of this pilot project. The pen-based computer may:

1. Provide field geologists with a durable means of digital data capture of geological information at source, thereby decreasing the reliance on handwritten notes and eliminating secondary data entry.

2. Ensure the greatest possible integrity to recorded field data, by recording data at source, and by the individual making the observations.

3. Maximize on-site data collection using a standardized data dictionary by presenting easy to use digital forms incorporating all geological information potentially present.

4. Advance the adoption of a standard database architecture for field mapping projects, thus facilitating potential dataset integration for synoptic or province-wide compilation studies.

ACKNOWLEDGMENTS

We thank Kevin Heather, Andy Fyon, Steve Jackson and Glen Johns for their contributions during various stages of this project. Special appreciation goes to Steve Jackson for his ongoing testing of the pen-based computer and software under field mapping conditions.

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Engineering and Terrain Geology Programs

22. Summary of Activities 1991, Engineering and Terrain Geology Section

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The activities of the Engineering and Terrain Geology Section includes the mapping, investigation and research of Paleozoic, Mesozoic and Quaternary rocks and deposits. These activities include not only the mapping of these rocks and the assessment of the mineral resources potential contained therein (such as sand and gravel, limestone, peat, salt, gypsum, etc…) but also the investigation of past and current geological processes which affect the occupation and use of the land by the residents of the Province.

PROGRAMME COMPONENTS 1991

Quaternary Geology Subsection

The mapping and related studies of the surficial geology of the Province is a long standing endeavour of the Section. Historically, mapping has been concentrated in and around population and development centres, in areas of high mineral potential and along ground transportation corridors, both existing and planned.

Two Quaternary projects with field components described in this volume, Barrie (P.J. Barnett) and Christian Island-Penetang-Gravenhurst (A.F. Bajc), are examples of work undertaken in areas of rapid growth and development. The surficial data base being created by the mapping in the Barrie area will serve to assist land use planning in rural areas experiencing low density urban development by identifying, among other things, aggregate resources and aquifers.

The study by Bajc, part of a larger program in the Huntsville-Penetang area, is being completed in co-operation with the Ontario Ministry of Natural Resources and the Regional Municipality of Muskoka. The aim of the project is to identify "heritage " areas; these being areas which are unique on several levels (geological, biological, etc...). Completion of the mapping will also allow an understanding of how the surficial geology relates to, or impacts upon, environmental concerns in this area.

Quaternary mapping in the Elliot Lake and Wawa areas of northern Ontario was undertaken by M.J. Ford and T.F. Morris, respectively. The inventory of the surficial materials in the area around Elliot Lake is now largely complete. A second phase of studies will now begin, focussing on testing the suitability of the glacial sediments for industrial and developmental purposes.

Two main objectives have directed the work in the Wawa area; mapping the Quaternary cover on the greenstone belt at a 1:50 000 scale, and assessing the use of various fractions of the glaciogenic sediments in drift exploration. The results of this project will form another layer in the geoscientific coverage of the area. This integrated regional database will serve to assist exploration.

The considerable effort by P.J. Barnett and others in the assembly of the 1:1 000 000 scale Quaternary geology maps of the province, prepared as part of the Geology of Ontario project, came to fruition with the release of 4 maps in October. These maps compliment Barnett's Quaternary chapter in the Geology of Ontario volume, due out next year.

Paleozoic/Mesozoic Geology Subsection

The objective of the Paleozoic/Mesozoic mapping program is to supply an up-to-date geoscientific data base on rocks of this age in Ontario. This data base serves a dual role. Firstly, it assists in encouraging the exploration, development and utilization of the Paleozoic and Mesozoic deposits. Secondly, the environmental impact resulting from current or proposed use of these rocks can be assessed.

The drilling program completed under the supervision of D.K. Armstrong is a prime example of the first objective. The drilling will add to the surprisingly sparse knowledge base of the subsurface geology of the Lake Simcoe area. Perhaps more importantly, it will provide information on the distribution and stratigraphic position of alkali-reactive beds present in the area. Use of the quarried rock from the area is restricted by this problem.

The completion of a chapter for the Geology of Ontario volume on the Paleozoic/Mesozoic geology of the province was the major commitment of the staff of the Subsection. D. Armstrong, M. Johnson and M. Rutka have had the lead roles in the assembly and interpretation of the post-Precambrian carbonate and siliciclastic rocks of the province. The chapter will provide a standard reference for the foreseeable future.

Aggregate Assesssment Inventories

The role of the Aggregate Assessment Office (AAO) is to provide technical and geoscientific information on the aggregate resources of the province. This information is vital when considering planning and land use options during the formulation or review of Official Plans. The inventory portion of the AAO is augmented by research into non-traditional data collection techniques (i.e. surface geophysics) and collaborative efforts with outside agencies.

In 1991 the staff of the AAO reviewed data previously collected for a number of townships in southern Ontario. This information was updated in the course of preparing reports for publications. Studies in northern Ontario were also brought to completion. The most notable of these was the Moosonee Aggregate Resources Inventory, a project that had a large number of contributing agencies including the Ontario Ministries of Natural Resources and Transportation.

The review of the Niagara Escarpment Plan also impacted upon the AAO staff. Participants with interests in the Plan review were supplied with aggregate resource data and associated information for those areas affected by the proposed changes. New information was released for the townships along the Bruce Peninsula.

Applied Research

Applied research projects undertaken by the Engineering and Terrain Geology Section are designed to better evaluate both mineral resources and the geological processes which may affect human occupation and use of the land base. The later includes the provision of geoscientific information on a range environmental issues.

An initiative of the Section this past year was a soil radon gas survey in selected areas of southern Ontario. Designed as a pilot project, the work is attempting to investigate the geological controls on the distribution and level of radon gas in the soil profile. The survey is the first of its kind in Ontario and as such will assist in determining what the background levels of the soil radon gas are in several different geological environments.

The investigation of the Sheguiandah archeological site is an example of the role geological studies play in interpreting the record of human history in the Americas. The presence of artifacts beneath a diamicton previously identified as glacial till was cited as evidence of early (Pre-Late Wisconsinan) human occupation in Ontario. The expertise provided by P.J. Barnett in his examination of the materials at the site assists in resolving the issue of when and under what conditions the site was occupied.

23. Project Unit 86–13. Quaternary Geology of the Barrie Area, Simcoe County, Ontario

P.J. Barnett

Engineering and Terrain Geology Section, Ontario Geological Survey

INTRODUCTION

Field mapping of the Quaternary geology in the southern part of the Barrie map area (NTS 31 D/5) was conducted this past summer. This completes the field work associated with the study of the Quaternary geology of the Barrie–Elmvale area (Barnett 1986).

The area studied occurs within the Town of Innisfil and Essa and Vespra township municipalities (*see* Figure 1). The area consists of an upland bordered by large valleys partly occupied by Cook's and Kempenfelt bays of Lake Simcoe. The upland is part of the Simcoe Uplands physiographic region of Chapman and Putnam (1984); the valleys, the Simcoe Lowlands. A large valley, now occupied by the underfit Lovers and Innisfil creeks, bisects the upland in the Town of Innisfil. The large valleys have been previously interpreted as tunnel valleys (Barnett 1986, 1990).

FINDINGS

The upland surface consists of streamlined forms, predominantly drumlins, which are oriented generally toward the southwest. Drumlins, composed mainly of a sandy silt till, form the peculiar headlands along the shoreline of Cook's Bay.

A variety of ice stagnation forms of various scales surround the streamlined forms. The ice stagnation forms range from broad moraine plateaus (landforms developed as the result of ice-walled lakes) and open channel eskers to low-relief, sinuous ridges, referred to by Deane (1950, p.97) as "ice block ridges". The larger forms tend to occur on the top of the upland surface and the smaller forms in lower areas along the upland flanks.

Shoreline erosion and deposition associated with ancestral glacial lakes has produced spectacular shorebluffs, beaches and spits in the area. The predominant forms relate to the "Main Phase" of glacial Lake Algonquin. Higher, weakly-developed abandoned shorelines are present in the area, but they are not as well developed as those north of Kempenfelt Bay (Barnett 1989). Deposits and landforms of some of the lower levels of glacial Lake Algonquin also occur.

The edges of the upland are severely gullied, particularly the upland area west of Lovers Creek. Gullying appears to be controlled by the stratigraphy of the area and local groundwater flow patterns.

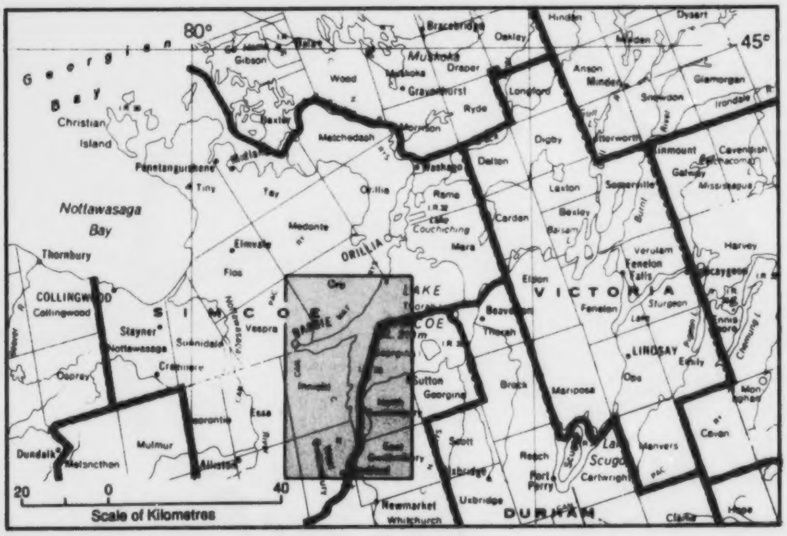
80°
45°
Georgian Bay
Christian Island
Gibson
Wood
Muskoka
Draper
Gravenhurst
Bracebridge
Oakley
Ryde
Baxter
Matchedash
Morrison
Penetanguishene
Tiny
Tay
Orillia
Washago
Rama
Lake Couchiching
Mara
Nottawasaga Bay
Medonte
Elmvale
ORILLIA
Flos
Thornbury
COLLINGWOOD
Collingwood
SIMCOE
Stayner
Nottawasaga
Sunnidale
Vespra
Oro
BARRIE
Innisfil
Essa
Creemore
Osprey
Tecumseth
Mulmur
Dundalk
Melancthon
Alliston
Newmarket
Whitchurch
LAKE SIMCOE
Sutton
Georgina
Beaverton
Thorah
Scott
Uxbridge
Brock
Reach
Port Perry
Lake Scugog
Cartwright
DURHAM
Hindon
Dysart
Minden
Anson
Glamorgan
Snowdon
Irondale
Longford
Digby
Dalton
Laxton
Carden
Bexley
Balsam L
Somerville
Burnt River
Kinmount
Galway
Cavendish
Mississagua
Harvey
Verulam
Fenelon Falls
Eldon
VICTORIA
Fenelon
Sturgeon Lake
Bobcaygeon
Ennismore
Chemung L
LINDSAY
Emily
Ops
Mariposa
Manvers
Cavan
Monaghan
Clarke
Hope
20
0
40
Scale of Kilometres

Figure 1. Location map of study area, scale 1:1 584 000.

Surface sediment distribution is closely associated with the distribution of landforms. However, these relationships are complicated by the generally thin and discontinuous nature of the surface sediments and by the extensive postglacial gullying that has occurred in the area. The landforms in the Barrie area are not typical of the landscape of much of Ontario, where ice marginal retreat was sequential. The distribution of landforms and sediment types in the study area represent an environment of regional ice stagnation with the development of enlarged crevasses that probably contained ice-walled lakes and streams.

Stratified sediments, predominantly sand and sandy gravel (some minor deposits of silt and clay), are associated with the larger stagnant-ice forms. They occur in irregular-shaped, positive-relief bodies, generally overlying till. Where these sediments and landforms are absent, till is the surface sediment.

The till on the upland surface varies in matrix grain size from sand to sandy silt. It is poorly sorted and commonly stony. The till is interpreted as having been deposited subglacially predominantly by meltout and flow processes. The base of the till is commonly interbedded with underlying sand and gravel.

The sand and gravel deposits beneath the till were deposited in contact with the glacier. They consist of trough cross-bedded sand and gravel in deep channel-shaped scours or as plane-bedded sand in laterally extensive sheets. The deposits are inset into finer grained glaciolacustrine sand and silt deposits as observed in several pits and excavations in the area. The sands and gravels may have been deposited by sheet or channelized flows during a catastrophic release of subglacially stored meltwater during an early stage of tunnel valley formation (Barnett 1986, 1990). The occurrence of these ice-contact sand and gravel deposits beneath the till appears to be patchy and the prediction of their location is difficult.

Glaciolacustrine sands and silts directly underlie the ice-contact deposits or the surface till. They are in turn underlain by glaciolacustrine silts and clays; commonly rhythmically bedded. The occurrence of fine-grained glaciolacustrine sediments beneath permeable sands, and sands and gravels has influenced local groundwater flow and the location of gully development. Groundwater seepage and piping of sands along valley walls probably formed the extensive network of gullies that occur in the map area.

Below the shorebluff of the Main Phase of glacial Lake Algonquin, the surface till has a predominantly sandy silt to silt texture. It has been seen to overlie glaciolacustrine sediments, as well as, sandy lodgement till.

Clayey diamictons, commonly interbedded with deformed laminated fine-grained sediments, occur above the Algonquin shoreline in association with the "ice block ridges" of Deane (1950). Essentially deformed glaciolacustrine sediment, they may represent a later ice advance into the area (Kettleby Till?) or they may be a product of a later stage of ice disintegration when greater amounts of standing water existed and ice bergs may have been abundant. Sandy and silty till, gravel, sand and silt can also be observed in these distinctive landforms.

Several localities of fossil-bearing silts, deposited in lagoons of glacial Lake Algonquin, were found and sampled.

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24. Project Unit 89–54. Geological Investigations at the Sheguiandah Archeological Site, Sheguiandah, Ontario

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INTRODUCTION

Much controversy surrounds the age of the artifacts and the origin of the encasing sediments at the Sheguiandah archeological site. The sediments containing the artifacts have been interpreted as till by Thomas E. Lee, the original archeologist at the site. He reports, (Lee 1978), that several distinguished geologists and Quaternary geologists, including Dr. Ernst Antevs, had visited the site and supported this interpretation. Lee (1978) suggested that the artifacts and human occupation of this site date to before the last glacial advance in the area, possibly 30 000 years ago. However, Dr. Jack Hough, suggested that the sediment containing the artifacts were mudflows, not tills, and that the occupation of the site must have been after the draining of glacial Lake Algonquin (Lee 1978).

Location and Present Investigations

The Sheguiandah site is located immediately north of the hamlet of Sheguiandah on Manitoulin Island. The site consists of several small quartzite quarries and a habitation area situated on a bedrock-controlled hill.

The present archeology investigations include: 1) removing the backfill from the original trenches of Thomas Lee; 2) excavating along the walls of Lee's original trenches; 3) collecting and cataloging new found artifacts; 4) re-surveying the site; and 5) examining bedrock surfaces and quarry faces.

Geological investigators at the site include: Dr. Peter Von Bitter, Royal Ontario Museum, who is investigating the bedrock geology of the site and surrounding area, Dr. Bill Mahaney, York University, who has analyzed grain-size distributions and grain textures, by scanning electron microscopy, on samples collected previously by Thomas Lee and will be analyzing future samples from the site as well; and Dr. Paul Karrow, University of Waterloo, who will assist with the postglacial lake history of the area. The author was asked to study the sedimentology and stratigraphy of the Quaternary sediments at the site in order to determine their origin and age.

Geological Setting

The Sheguiandah site is located on a ridge of Precambrian white quartzite. One of a series of quartzite inliers, it protrudes through the cover of shale and carbonate rocks of Paleozoic age in the vicinity of Sheguiandah. The Paleozoic succession includes a basal quartzite boulder conglomerate which is overlain in places by the Lindsay Formation, a grey, finely crystalline limestone. The Lindsay Formation limestones are

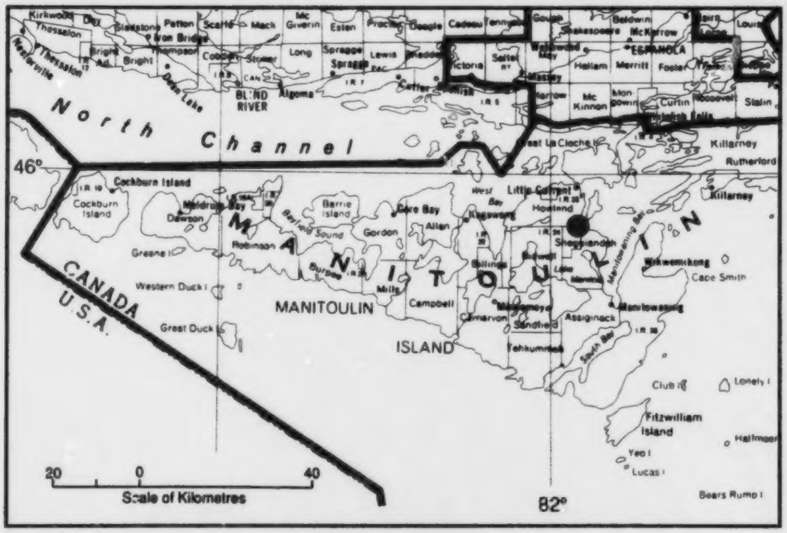
North Channel
46°
82°
CANADA
U.S.A.
MANITOULIN ISLAND
BLIND RIVER
Thessalon
Algoma
Cockburn Island
Barrie Island
Gore Bay
Gordon
Allen
West Bay
Little Current
Howland
Sheguiandah
Wikwemikong
Cape Smith
Manitowaning
Assiginack
Sandfield
Tehkummah
South Bay
Mindemoya
Carnarvon
Campbell
Mills
Robinson
Dawson
Meldrum Bay
Greene I
Western Duck I
Great Duck I
Killarney
Rutherford
Espanola
Fitzwilliam Island
Club I
Lonely I
Yeo I
Lucas I
Bears Rump I
20 0 40
Scale of Kilometres

Figure 1. Location map of study area, scale 1:1 584 000.

overlain by shale and carbonate rocks of the Collingwood Member of the Lindsay Formation, the Blue Mountain Formation and the Georgian Bay Formation. These bedrock formations dip gently southward toward the center of the Michigan Basin. Generally, north-facing bedrock-controlled escarpments have formed in the area as a result of differential erosion and weathering of these various rock types.

The drift cover over much of Manitoulin Island is thin. Bedrock commonly outcrops or is covered by a veneer (less than 1 m) of glacial or glaciolacustrine sediments. The drift cover is locally thick in the re-entrant valley at Sheguiandah. The direction of ice flow across the eastern part of Manitoulin Island averages 220° (Chapman and Putnam 1984). The orientation of drumlins and large grooves cut into the bedrock surface (observed on airphotos of the area) are between 220° and 240°. Striations on quartzite outcrops on the northern edge of the site were oriented approximately 230°.

Only one till has been recognized on the Island to date, with the exception of the multiple till layers reported at the Sheguiandah site by Dr. Lee. Abandoned shoreline features and their deposits are well preserved and record the postglacial lake history of the area (Tovell 1978). Abandoned shorelines of most of the post-Main Algonquin phases are in the immediate vicinity of Sheguiandah and are recognizable on airphotos.

PRESENT SURVEY

The present investigation included the description and sampling of materials exposed in two of the re-excavated trenches of Thomas Lee, and three roadcuts in the immediate vicinity of the archeology site. Pebble counts were collected from all till exposures investigated.

Off-Site Results

Two till exposures in roadcuts were examined, described and sampled. Samples were collected from each soil horizon developed in till, in order that laboratory results could be compared directly to the weathered samples collected on site. In each exposure, only one layer of till was observed. The till at each site, however, was very different in appearance; primarily the result of the different underlying bedrock at each site.

The till exposed at site Sheg 1 is a compact, fissile, gritty fine sandy silt. It contains between 5% and 10% clasts ranging in size from granules to boulders. Some boulders were bullet-shaped and extensively striated. Pebble counts at two levels in the till contain high amounts of locally derived clasts from the Georgian Bay, Bobcaygeon and Blue Mountain formations, with an increase in the proportion of Georgian Bay Formation clasts in the upper part of the exposed till. The till is interpreted as subglacial lodgement till.

At site Sheg 3, the till was a compact, blocky clayey silt containing some very coarse sand grains and granules. Clast content was less than 1%, consisting of predominantly pebbles and cobbles; boulders are rare. Pebble are also derived locally, however, at this site, over 80% of the clasts were derived from rocks of the Collingwood Member of the Lindsay Formation and the Blue Mountain Formation. The till matrix at this site is very local, derived primarily from the crushing of shales which it overlies. The lower contact of the till with the underlying shale is difficult to find because of a zone of deformation till or glacially deformed shale, which, in places, can exceed 1.5 m in thickness.

An abandoned shoreline deposit, consisting of imbricated boulder gravel in a "dirty" coarse to very coarse sand matrix, was also sampled for comparison purposes (Sheg 2).

Sheguiandah Site Test Pits 7–8 (SW) and 8–B

The lowermost unit in test pit 7–8 (SW) is a mottled grey, brown and orange, matrix-supported diamicton. Its matrix is a gritty silty sand which appears to be massive or fissile. Pebbles and cobbles make up between 1% and 5% by volume. Boulders are rare, but present in the exposure. Pebble shapes range from angular to rounded. Thirty percent of the pebbles are black shale and 23% are angular quartzite fragments, likely from local sources. This massive diamicton is interpreted as subglacial till.

Stratified silty fine and very fine sands containing lens-shaped bodies of a silty sand diamicton, interpreted as debris flows (flowtills ?), were found resting directly on bedrock(?) in Lee's test pit 8–B. Subglacial till was missing in this pit. It may, however, be present at depth below the bottom of test pit 8–B, if the exposed quartzite was a large boulder rather than the bedrock surface. The stratified sands are most likely younger than the till and likely record local deglaciation of the site. Both units are overlain by boulder gravels.

The till in test pit 7–8 (SW) is overlain by a thin boulder gravel layer or lag. The contact between the till and gravel is sharp, but has relief of up to 10 cm. The till-gravel contact also coincides with a geochemical boundary between a highly oxidizing environment in the upper layers of the test pit and a predominantly reducing environment in the till. Root systems are extensively developed in the coarser grained, oxidized sediments overlying the till.

The gravel layer consists of predominantly boulder-sized rock fragments in a fine- to medium-grained sand matrix. The boulders, predominantly igneous or metasedimentary rocks, were primarily derived from the Canadian Shield north of Manitoulin Island. However, locally derived shale, quartzite and calcareous sandstone boulders make up over 30% of the boulders present. Approximately 18% of the boulders in the gravel layer were striated on their tops; some having two well-preserved sets. Striation orientation was not consistent between boulders and ranged from 195° to 348°. Boulder shapes range from angular (particularly quartzite boulders) to well rounded (granites/granodiorites and shales). Some boulder surfaces were very irregular due to differential weathering of the component minerals. The overall surface of the boulders is irregular with relief between boulder tops in the order of 15 to 20 cm. The orientation of boulders was fairly random, however, tabular-shaped boulders generally dipped to the northeast. Two boulders appeared to be imbricate with both dipping toward the northeast.

A subglacial origin for the boulder gravel, such as a boulder pavement, is not supported by the above-noted characteristics. The irregular upper surface of the boulder layer, combined with the low number of boulders with striated tops and the inconsistency in the direction of these striation, are evidence against such a conclusion. The distally derived nature of the boulders in the gravel layer compared to the pebbles in the underlying till suggest that this material may have been carried englacially and deposited during the final stages of deglaciation. They may have been deposited as a boulder lag or have been deposited in the upper part of the till and subsequently eroded out by glaciofluvial or glaciolacustrine processes.

The boulder gravel is overlain by a generally coarsening upward sequence of sand and gravel which has been subdivided into 3 units in the past by Thomas Lee (till 1, till 2 and a sand and gravel layer). The material above the boulder layer, however, appears to be fairly well-sorted, subrounded to rounded, coarse to very coarse sand and granule gravel. The upper two units contain angular to rounded pebbles and cobbles. The content of silt and clay within the sand and gravel gradually increases upward. Although this may be the result of depositional processes, it is suggested here, that this increase in fines is the result of soil-forming processes and the weathering of some of the constituent rock fragments (shale and phyllites) in the sand and gravel. Loess may also have been incorporated in to the upper 30 cm of the soil.

Similarly weathered, coarse-grained sand and gravels were observed in a roadcut through a beach deposit west of the site (station Sheg–2, a beach of the Payette phase (?) of glacial Lake Algonquin). The upper sediments of questionable origin in the 2 test pits (till 1 and 2 of Lee) are most likely highly oxidized and weathered nearshore or beach deposits of a postglacial lake, probably the Korah phase of glacial Lake Algonquin. Korah phase shoreline features occur approximately 14 m above shoreline features of the Nipissing Great Lakes on Manitoulin Island (Cowan 1985). The Nipissing shoreline is at an elevation of approximately 200 m at Sheguiandah.

The upper sediments may have been deposited in a partially sheltered embayment of this lake. The "Mystic Ridge", partially cored by a quartzite boulder conglomerate, is covered by approximately 0.5 m of boulder gravel immediately south of the test pits. Its elevation, above that of the area of the test pits may have partially protected the test pit area from the full force of waves and currents from the south and southwest. However, the Mystic Ridge decreases in elevation to the east and northeast and becomes lower in elevation than the area of test pits. This may have allowed wave and current access from the east and northeast and may explain the general northeastward-dipping orientation of the tabular boulders of the gravel lag. The quartzite ridge (inlier), itself, would protect the test pit sites from wave attack from the remaining directions.

CONCLUSIONS AND RECOMMENDATIONS

Based on field examinations, the sediments referred to and identified as till 1 and 2 by Thomas Lee are probably not tills. Neither are they debris flows, as suggested by Hough. These sediments of questionable origin are most likely highly oxidized and weathered nearshore or beach deposits of a postglacial lake, probably the Korah phase of glacial Lake Algonquin.

The general record of sediments preserved at the site suggests that only one subglacial till layer occurs at the site and is located below the artifact-bearing layers. The debris flows (flowtills ?) interbedded with the stratified silty fine and very fine sands are probably younger than the till and likely record local deglaciation of the site. The boulder gravel truncates both these units and may be a lag produced by the erosion of till and bedrock units exposed within wave base of the ancestral postglacial lake. The overlying sand and gravel layers are thought to be beach or nearshore sediments deposited in a partially protected embayment. Their fine component is probably the result of *in situ* weathering and possibly the mixing of a thin surface deposit of loess with the beach sediments by human disturbances. Artifacts found within the beach sediments are probably less than 10 000 years old.

The above results and conclusions are preliminary and are based solely on field observations. They may change as additional information, such as laboratory results on grain size distribution, are obtained. It is recommended that the area surrounding the site be mapped in greater detail. Local variations in till could be documented, exposures of multiple tills may be observed and ancestral shoreline features identified and better defined.

ACKNOWLEDGMENTS

The author would like to thank Dr. Peter Storck of the Royal Ontario Museum, Dr. Pat Julig of Laurentian University and Dr. Ron Williamson of Archeological Services Inc. for the opportunity to investigate the geology of this interesting and significant archeological site.

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25. Project Unit 90–33. Quaternary Geology of the Christian Island, Penetanguishene and Gravenhurst Areas.

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INTRODUCTION

Detailed Quaternary geology mapping of the Christian Island (41 A/16), Penetanguishene (31 D/13) and Gravenhurst (31 D/14) 1:50 000 scale maps of the National Topographic System was undertaken during the 1991 field season (*see* Figure 1). This work completes the second year of a mapping program which also includes the Huntsville (31 E/6) and Bracebridge (31 E/3) map areas to the north (Bajc 1990, 1991).

Funding for this program was provided by the Ontario Ministry of Natural Resources, the District Municipality of Muskoka and the Ontario Geological Survey. In addition to providing a data base of Quaternary geology, candidate sites were identified and will be considered for protection under the Areas of Natural and Scientific Interest (ANSI) Program of the Ontario Ministry of Natural Resources and the Muskoka Heritage Areas Program of the District Municipality of Muskoka.

BEDROCK GEOLOGY

Much of the study area east of Georgian Bay lies within the Central Gneiss Belt of the Grenville Province; a structural subdivision of the Canadian Shield (Wynne-Edwards 1972). The belt consists mainly of quartzofeldspathic gneisses and migmatitic rocks which have been metamorphosed to upper-amphibolite and, locally, to granulite facies. A strong, northwest-trending structural grain in the bedrock is manifested by parallel sets of long, narrow lakes and wetlands over much of the map area.

The Precambrian–Paleozoic contact lies beneath Georgian Bay. Its exact position is unknown, however, it likely occurs along the northern edge of Simcoe County and extends southeastward along Severn Sound to Waubaushene. To the east, near Sparrow Lake, a small segment of the contact extends northward into the map area (specifically, NTS map 31 D/14). Several small Paleozoic outliers occur near Honey Harbour, Port Severn, Matchedash Bay, Coopers Falls and Uphill (Liberty 1969).

The Paleozoic sequence consists primarily of the Middle Ordovician, Shadow Lake and Gull River formations. Red and green shales, siltstones and arkoses of the Shadow Lake Formation are overlain by lithographic to sublithographic limestones of the Gull River Formation. Fine-grained, argillaceous limestones and calcarenites of the Bobcaygeon Formation (also Middle Ordovician in age) overlie the Gull River Formation south of Sparrow Lake (Liberty 1969).

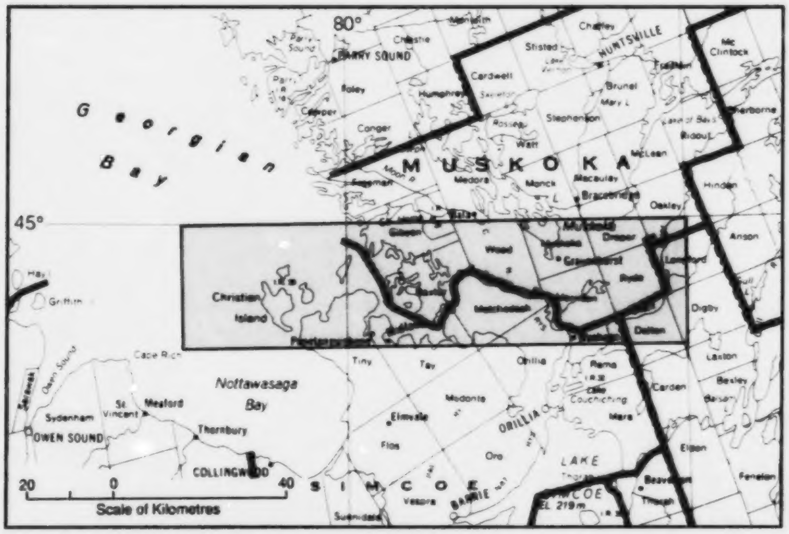
80°
45°
Georgian Bay
MUSKOKA
SIMCOE
PARRY SOUND
HUNTSVILLE
Christian Island
Penetanguishene
Nottawasaga Bay
OWEN SOUND
COLLINGWOOD
ORILLIA
BARRIE
Meaford
Thornbury
Gravenhurst
Bracebridge
Matchedash
Tiny
Tay
Medonte
Oro
Orillia
Mara
Rama
Carden
Dalton
Ryde
Wood
Morrison
Draper
Macaulay
Monck
Medora
Watt
Stephenson
Humphrey
Conger
Foley
Cowper
Christie
Cardwell
Stisted
Chaffey
Brunel
McLean
Oakley
Hindon
Anson
Digby
Laxton
Bexley
Eldon
Fenelon
Sunnidale
Vespra
Flos
Elmvale
Sydenham
St. Vincent
Lake Simcoe
20 0 40
Scale of Kilometres

Figure 1. Location map of study area, scale 1:1 584 000.

PHYSIOGRAPHY

Two distinct physiographic regions have been identified within the map area. These are: 1) a low-relief, gently sloping, driftless plain; and 2) a gently undulating, drift-covered upland cut by steep erosional scarps and broad, north-trending valleys.

The driftless plain, referred to by Chapman and Putnam (1984) as the Georgian Bay Fringe physiographic region, occupies the area underlain by Precambrian bedrock. Aside from a few isolated areas, Quaternary deposits are largely absent. Where they do exist, Quaternary deposits are extremely thin and discontinuous. The land surface of this physiographic region slopes gently and evenly to the southwest from an elevation of 350 m above sea level in the northeast to 177 m above sea level (mean level of Georgian Bay) in the southwest. Northwest-trending bedrock ridges provide 15 to 20 m of local relief in this area.

The second physiographic region is located south of the Precambrian–Paleozoic contact and includes the Penetang peninsula and Giants Tomb, Beckwith, Hope and Christian islands. Drift thickness is variable within this area. Limestone of the Gull River Formation outcrops over much of the area north of Port McNicoll. Drift thickness increases rapidly to the west where water-well records indicate an overburden thickness in excess of 150 m. The physiography of this area is a result of glacial and postglacial erosion and deposition. Elevations range from 328 m above sea level at Lafontaine Hill to 177 m above sea level at Georgian Bay. Wave-cut notches formed by ancestral, Huron-basin lakes reach heights of 50 m. Broad, north-trending, U-shaped valleys transect the landscape and reach widths of 2 to 3 km and depths of 100 m or more.

QUATERNARY GEOLOGY

The sediment record encountered within the 2 physiographic regions described above are quite different. The Precambrian shield east of Georgian Bay contains a sediment record that was produced mainly during deglaciation of the map area, approximately 11 000 years ago. To the west, areas underlain by Paleozoic bedrock contain a more complex sediment record. Older drift packages, of unknown age, were identified within sections cut into remnant upland areas.

Striated bedrock surfaces and fluted till plains indicate that glacial ice flowed towards 190° during the latest ice advance. Glacial Lake Algonquin expanded northward as the Late Wisconsinan ice margin retreated from the map area. The majority of the deposits and facies transitions observed in the map area reflect this glaciolacustrine environment of deposition. Fluctuating Huron basin water levels occurred in response to the opening and closing of outlets. Glaciolacustrine landforms and deposits record these water-level fluctuations and account for a significant proportion of the area's surficial geology. Since the Precambrian-shield and Paleozoic terrains display such distinct Quaternary-sediment packages, they will be discussed separately in the following sections.

Shield Terrain

Much of the shield terrain consists of areas that contain either no drift or a very-thin, discontinuous veneer of till and/or glaciolacustrine sediment. The bedrock surface is often heavily weathered and lacks glacial polish. Subglacial water-erosion forms, as exist to the north along the shores of Georgian Bay (Kor et al. 1991), are not common. Remnant pockets of till have been observed locally. The till is often sandy, deeply weathered and may be washed in the uppermost metre of its vertical section. In places, the till has been completely removed by lacustrine processes leaving nothing more than scattered boulders upon a bare bedrock surface. The till cover becomes more locally extensive toward the northeast where it has been observed to reach thicknesses of 2 to 3 m. Most of these accumulations represent stacked ice-marginal debris flows.

Two south-trending systems of subaquatic fans mark the former routes of subglacial drainage occurring within the area of the Gravenhurst map sheet. Each system can be traced northward into the adjoining Bracebridge and Huntsville map-sheet areas (Bajc 1990, 1991). The first, and most important system economically, follows the Highway 11 corridor between Muskoka Falls and Severn Bridge. With the exception of a few deposits existing between Gravenhurst and Muskoka Falls which contain coarse, crushable aggregate, most of this system is composed of fine to very-fine sand and pebbly, fine to medium sand. To the east, a second system can be traced from Uffington southward to Coopers Falls. This series of deposits is sandy for the most part as well.

Distal, subaquatic fan deposits grade both laterally and vertically into horizontally laminated sands and silts of glacial Lake Algonquin. Laminated silts and clays can be found in isolated topographic depressions away from the main fan systems.

Nipissing-transgressive sediments are found below 195 m above sea level. They are situated primarily in low-lying areas north and east of Matchedash Bay. In these areas, the sediments consist of well- laminated silts with minor clays and fine to very-fine sands. Fossil plant and mollusc remains have been encountered at numerous sites in Nipissing-beach sediments. During the preceding low-water stage of Georgian Bay (Lake Hough), peat and limnic sediments accumulated in isolated topographic lows below the elevation of the Nipissing shoreline and were later buried during the Nipissing transgression. Several buried, organic deposits have been found within the lowland surrounding Matchedash Bay.

Paleozoic Terrain

The area underlain by Paleozoic bedrock consists of upland regions transected by broad, south-trending, U-shaped valleys. These valleys extend southward into the Barrie and Elmvale map-sheet areas where they have been interpreted as tunnel valleys carved subglacially by the catastrophic release of ponded, subglacial meltwaters (Barnett 1986, 1990).

The upland areas are cored with at least one fine-grained till unit and interbedded glaciofluvial and glaciolacustrine sediments. The ages of these sediments are unknown. The fine-grained till is silty, stone poor and contains 85% to 90% Paleozoic carbonate clasts in the pebble-size fraction. The fine-grained nature of the till matrix and the abundance of Paleozoic carbonate clasts suggest a northwesterly source for the till.

The youngest drift unit consists of interbedded flow tills and stratified sands and silts. A massive, slightly fissile facies of this till, probably a subglacial facies, has been encountered at several sites within this region. The entire drift package drapes an older surface. The large, north-trending valleys were carved prior to the deposition of the upper drift package. The till plain is fluted on top of Lafontaine Hill and drumlinized to the east near Port McNicoll. The till is typically sandy, stone poor and contains 40% to 50% Paleozoic carbonate clasts in the pebble-size fraction. The till becomes progressively stonier to the east where the drift thickness is less.

The broad, north-trending valleys are filled primarily with sandy to silty glaciolacustrine sediments and interbedded debris flows. Glaciolacustrine sequences up to 30 m in thickness were observed in Nipissing-bluff sections which occur along the extreme western edge of the Penetang peninsula.

Upland areas were wave modified up to the prominent main Lake Algonquin shoreline which is situated at 260 m above sea level. Higher shorelines were not identified. Steep cliffs occur where fine-grained or relatively resistant sediments such as till or glaciolacustrine silts and clays overlie glaciofluvial and glaciolacustrine sands. Groundwater, piping at the base of several Lake Algonquin bluffs, has created large amphitheatre-shaped erosional scars.

The glacial landscape below the main Lake Algonquin shoreline was extensively modified by nearshore processes. Surface sediments resulting from the reworking of the surface till sheet consist primarily of beach and nearshore sands and gravels. Quiet-water environment silts and clays are limited in distribution and occur primarily within the broad plain due north and west of the hamlet of Lafontaine.

Boulder lags are common along the bases of west-facing bluffs on the Penetang peninsula. The boulders are probably derived from the erosion and winnowing of till contained either within or at the base of the bluffs.

Beausoleil, Giants Tomb, Beckwith, Hope and Christian islands are all situated below the main Lake Algonquin level. They have been extensively modified by nearshore processes because of their exposed location. These islands are probably cored, at least in part, with till, although beach and nearshore sediments are present at the surface.

The Nipissing transgression is well recorded along the shore areas of Severn Sound because of its protected position. Several sites containing buried organic remains were encountered during the course of mapping and these were sampled for further work.

Large, cliff-top dunes were identified at the top of the Nipissing bluff in Awenda Provincial Park. The dunes reach heights of 10 to 20 m in places and are, for the most part, stabilized.

ECONOMIC GEOLOGY

Reserves of high-quality, coarse, crushable material are rapidly being depleted from the study area. The largest deposits occur along the Highway 11 corridor where the coarse, core sediments of subaqueous fan deposits exist. Unfortunately, large volumes of fine glaciolacustrine sediments often overlie these deposits making extraction difficult. The coarse aggregate along this corridor is considered hard and durable and is generally suitable for most usual applications (OGS 1990).

Sandy facies of subaquatic fan deposits are being used primarily as a source of fill and for the construction of septic beds in rural and cottage areas.

Several glaciofluvial deposits are currently being excavated on the Penetang peninsula. These large deposits, some of which underlie the youngest till sheet, consist mainly of durable, Precambrian gneissic and Paleozoic carbonate clasts.

Nearshore-beach and bar sediments have been utilized on Christian Island. These are the only aggregate types available. Extraction of several Lake Algonquin and Nipissing nearshore deposits is ongoing on the Penetang peninsula as well.

High-quality aggregates are being produced at several bedrock quarries in the map area. Quartzofeldspathic gneiss is being crushed in a quarry off of Highway 69, just west of Gibson Lake. Limestone products are currently being produced at two quarries along the southern edge of the Penetanguishene and Gravenhurst map-sheets area.

ACKNOWLEDGMENTS

The author would like to thank the Mohawks of Gibson, Beausoleil First Nation, the staff of both Awenda Provincial Park and Georgian Bay Islands National Park and numerous land owners for allowing us access onto the respective properties.

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26. Project Unit 90-35. The Quaternary Geology of the Rawhide Lake Area, District of Algoma

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INTRODUCTION

This project is part of a four-year program of geological mapping and geochemical surveys in the Elliot Lake region as part of the Elliot Lake Geological Re-assessment Project.

The Rawhide Lake map area (NTS 41 J/10; *see also* Figure 1) lies between latitudes 46°30'N and 46°45'N and longitudes 82°30'W and 83°00'W and encompasses about 1040 km^2. Provincial highways 546 and 639 provided major access, supplemented by forestry roads, trails, and water access on lakes by canoe and power boat. Pace-and-compass traverses were carried out in remote areas of special interest.

Previous geological work in the area includes bedrock mapping by Robertson (1963, 1968, 1977a, 1977b), Wood (1975) and Siemiatkowska (1977). A broad, regional reconnaissance study of surficial geology by Boissonneau (1965, 1968) included the present study area. As part of the present program, F.W. Breaks (this volume) began a reconnaissance study of Archean granitoid rocks in the region and M.C. Rogers (this volume) re-examined Archean supracrustal rocks in the southern part of the map area.

BEDROCK GEOLOGY

The Rawhide Lake map area lies on the boundary between the Southern and Superior structural provinces of the Canadian Shield. Major structures within the area include the Quirke syncline and the Flack Lake fault. The axis of the Quirke syncline trends east-southeast from its closure south of Lillybet Lake, passing out of the area at Dunlop Lake. The Flack Lake fault is a late, high-angle to vertical fault that strikes southwest through Hughson and Hembruff townships, turns westerly at Semiwite Lake and continues to Speckle Lake. West of Speckle Lake, it again strikes southwesterly and then curves to the northwest beyond Endikai Lake.

Numerous other faults are present in the area, including the westerly striking Ompa Lake fault which joins the Flack Lake fault south of Flack Lake. The Quirke Lake thrust fault enters the area near Manfred Lake and strikes westerly to Ten Mile Lake. In the central and northern parts of the area, the major faults strike westerly and southwesterly, with a number of north- and northwesterly striking cross faults. These features played a significant role in controlling postglacial drainage and the distribution of glaciofluvial sediments.

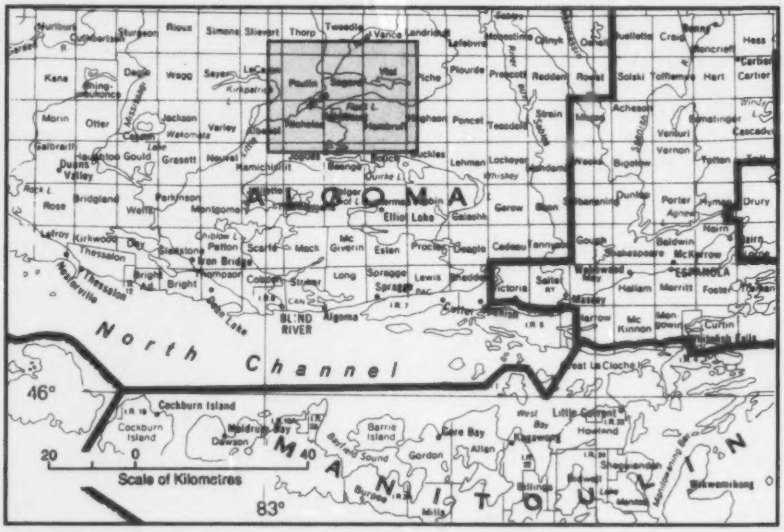

Figure 1. Location map of the Rawhide Lake area, scale 1:1 584 000.

The oldest rocks in the area are Archean supracrustal rocks; these consist mainly of mafic to felsic metavolcanic rocks and associated clastic metasedimentary rocks. These are found principally in a narrow, easterly striking belt that runs from just south of Fullerton Lake through Hembruff and Hughson townships. This belt, along with some younger Archean granitoid rocks, is bounded on the north by the Flack Lake fault. Small enclaves of Archean supracrustal rocks are present in the granitic terrane in the northern part of the area.

Late Archean grantitoid rocks underlie much of the northern part of the map area, as well as parts of Bouck, Buckles, Hembruff, Hughson, Beange and Raimbault townships. They are generally uniform, massive, medium- to coarsely crystalline, equigranular granite to quartz monzonite with only minor biotite. F.W. Breaks (this volume) has found three distinct grantitic masses that are probably parts of separate plutons. Just north and east of Rawhide Lake, the rocks are rich in mainly metasedimentary inclusions and are locally migmatitic and quite inhomogeneous, with small zones of pegmatite. Pegmatites are uncommon in the area and are composed simply of quartz and alkali feldspars.

Unmetamorphosed sedimentary rocks of the Early Proterozoic Huronian Supergroup underlie much of the map area and make up the bulk of the rocks in the Quirke syncline. Useful summaries of the stratigraphy and sedimentology of the Huronian Supergroup in the area can be found in Robertson and Card (1972) and Wood (1975). Within the syncline, there are rocks of the Hough Lake, Quirke Lake and lower Cobalt groups. These are principally repetitive sequences of clastic sedimentary rocks of probable fluvial, deltaic and nearshore marine origin that range from argillites and siltstone, through quartz and subarkosic arenites, to ortho- and paraconglomerates. Some of the matrix-supported conglomerates are thought to be of glacial origin. The Espanola Formation (Quirke Lake Group) contains interbedded siltsone and carbonate rocks.

North of the Flack Lake fault, a relatively complete sequence of Cobalt Group rocks underlies the area to as far north as Block's Pond in Sagard Township. These rocks generally dip gently to moderately southward, except for a few small open folds. The three upper formations of the group, the Bar River (youngest), Gordon Lake, and the upper Lorrain, are well exposed along Highway 639. These rocks include quartz and subarkosic arenites, quartz wacke, conglomeratic quartz wacke, siltstone and chert. Further north, there are numerous outcrops of the Gowganda Formation, stratigraphically the lowest formation in the group. It is an assemblage of arkosic sandstones and conglomerates, paraconglomerates with wacke matrices (diamictites), and laminated siltstones and lies unconformably on the predominantly granitic Archean basement.

The Huronian sequence, particularly the Cobalt Group rocks, have been intruded in several places by tholeiitic mafic sills (Nipissing diabase). In the thicker sills where magmatic differentiation occurred, the rocks range from gabbro upward to quartz diorite and granophyre. Nipissing diabase also overlies Archean granitoid rocks in the southern part of the area and may also form narrow dikes (Wood 1975). In much of the area, northwesterly striking olivine diabase dikes (the Sudbury swarm) cut the Nipissing diabase, Archean and Huronian rocks. These dikes seem to be cut by some of the late faults.

PHYSIOGRAPHY

The physiography of the area is largely bedrock controlled, with the many faults and other lineaments, and the major bedrock ridges acting as major landscape elements. The north-facing scarp of the Flack Lake fault is a prominent feature across much of the southern part of the area. In the central part of the area, the Nipissing diabase sills form prominent cuestas and hogback ridges that strike roughly easterly across the area. The most notable is "Boland Hill" between the Boland and Little White rivers and its eastward extension along the south shore of Rawhide Lake. Olivine diabase dikes form the cores of several northwesterly striking ridges near the east end of Rawhide Lake. The highlands in the northern part of the map area strongly reflect the underlying granitoid rocks and their rectilinear pattern of faults and master joints. Local relief exceeds 200 m in some parts of the area.

Most of the area is drained to the southwest by the Little White River and its tributaries, which include the Boland and Kindiogami rivers. The Little White River joins the Mississagi River southwest of the study area. The southeastern corner of the map area is drained southward via the Serpent River. The many lakes in the area lie in bedrock–controlled basins. The largest are Rawhide, Flack, Ten Mile, Mount and Semiwite lakes.

Locally, glacial and glaciofluvial landforms are important. There are low drumlinoidal features in Nicholas and Albanel townships, but well-formed drumlins are not present in the area. Small moraines, first noted by Wood (1975), are present east of Semiwite Lake in southeastern Poulin Township, and in the Boland River valley. Other ice-contact landforms are prominent in the Boland valley in Hembruff and Hughson townships and include esker complexes, crevasse fillings, and an ice-marginal delta. Extensive outwash plains are present in the Little White River valley, the Boland valley, east and northwest of Rosemarie Lake in Piche and Viel townships. There are series of erosional terraces in the Little White valley outwash in Sagard Township and near Distant Lake and west of Square Lake in Tweedle Township.

QUATERNARY GEOLOGY

All Quaternary sedimentary deposits in the Rawhide Lake map area are thought to be of Wisconsinan and Recent age. No older deposits were recognized and only three useful stratigraphic sections were found during the course of field mapping.

Striations, along with crescentic gouges and fractures, small-scale stoss-and-lee features, drumlinoid features, and till flutings, yielded many valuable ice-flow direction data. Two dominant directions were recognized: 175° (range 165° to 180°) and 195° (range 190° to 210°). Several sites with either intersecting striae or contrasting adjacent striations were found and, though not unequivocal, suggest that the 195° group represent the more recent flow direction. At three sites, clearly older 100° to 120° striations were found intersecting either the 175° or 195° sets. At one location in Nicholas Township, well-preserved striae, trending 240°, were found adjacent to 195° striations. The 240° set appears older, but this was not established conclusively. It is possible that the 110° set and the 240° striae are actually part of the same set, i.e., one is simply the reciprocal equivalent of the other. However, no indications of actual sense of movement were found for either of these two sets of striations. These variations in ice-flow directions can only be partly explained by local topographic deflection of the moving glacial ice.

The oldest known stratigraphic unit in the area is a sand to sandy silt till. Two general lithofacies were observed: a) a compact, relatively uniform matrix, 5% to 10% clasts, commonly with distinct fissility; and b) loose to moderately compact matrix, with sand lenses and stringers, substratified appearance, and up to 40% clasts. In profile, the weathered horizons in the till typically extend to depths of 0.7 to 1.0 m, are light yellowish brown, and generally are siltier and somewhat more stony than the fresh underlying material. The compact facies "a" ranges in colour from light olive brown to medium olive grey. Facies "b" is commonly very light grey to light olive grey in colour. It is thought that facies "a" was deposited mainly at the base of active glacial ice. The more complex facies "b" was probably deposited mainly as subaerial debris flows. In sections where both are visible, facies "b" always overlies "a". Other processes may have contributed to the formation of either of these facies.

Occurrences of glaciolacustrine sediments are limited within the area and do not form mappable surficial units. Laminated silt and fine sand and silt-clay rhythmites were found below glaciofluvial sediments in several sections in the Little White River valley and at one site north of the Boland River in Hembruff Township. Silt-clay rhythmites are exposed at surface at one site in northeastern Albanel Township. Couplet thickness ranges from 3 to 8 cm with abundant fine internal laminations in the silt layers and uniformly thin, 2 to 3 mm, clay layers. Minimum thickness of this deposit at this location is 3 m. The field evidence suggests that ponding occurred in the Little White River valley to as far east as the Poulin-Sagard township line and in the area of Stag Creek in Hembruff Township, possibly extending into adjacent Viel Township.

Deposits of glaciofluvial ice-contact stratified drift are composed of variable sand, gravel, and boulders, locally with minor silt or till. The positive landform features associated with these types of deposits occur in several locations within the area and have been previously mentioned in the physiography section. The small moraines in the area seem to be composed either of very bouldery material or largely of sand. The esker ridges in Hughson Township contain variable pebble and cobble gravels with coarse to very coarse sand, boulders, gravelly sand, and minor silt.

Glaciofluvial outwash deposits are common in low-lying areas throughout the map area. The outwash of the Boland River valley and the terraced deposits in the Little White River valley in Sagard Township are the most significant. The character and composition of these two outwash systems contrast sharply. The Little White River deposits are predominantly pebble and cobble gravels with the terraces indicating a series of erosional events. The Boland River outwash is mainly fine to coarse sand and lacks terraces, except in Hughson Township. Other important outwash bodies are present at Dougall Lake in Le Caron Township, along the Serpent River in Bouck Township, and near Square Lake and Distant Lake, both in Tweedle Township.

Lag deposits of boulders are common in the area. Notable lags occur: 1) along the Sister River in Sagard Township; 2) west of West Richie Lake in Viel Township; 3) south of Christman Lake in Mississagi Provincial Park; 4) in the southeastern part of Vance Township; 5) east of Reed Lake in Tweedle Township; and 6) along the Little White River in Albanel Township.

Many of the rivers and creeks in the area have significant Recent floodplain deposits that typically reflect the underlying Pleistocene sediments. Alluvial deposits along the Boland River are mainly sand and the river has constructed a delta at Mikel Lake roughly 1 km^2 in area. Well-sorted gravel deposits predominate along much of the Little White River.

Throughout the area, there are swamp deposits of muck and organic-rich silt. They are generally small, bedrock controlled, and occur along small streams. Far less common are bog deposits of sphagnum-derived peat. The only significant area of peat accumulation is the large bog east of Stag Creek in Hembruff Township. Peat thickness in the bog increases from less than 20 cm in the north to about 3 m at the centre. Thickness may increase further south toward the Flack Lake fault, which forms the southern margin of the basin. There are a few other small bogs in the map area.

Talus accumulations are common below the many bedrock scarps and steep hills. Talus cones and slopes typically display gravity sorting with the coarsest material near the base. This rock debris is angular and ranges from fine pebble size to large boulders. Locally, talus debris includes enormous blocks of up to 10 m maximum dimension. Other colluvial deposits include mixtures of angular local rock debris and glacial till. These are of restricted areal extent and are not considered mappable.

Drift thickness in the area is highly varible and available data are far too scanty to develop a comprehensive drift thickness map. Wood (1975) reported a diamond drill hole that penetrated 60 m of "variegated soil" near Stag Lake in Hembruff township. Till sections up to 10 m thick were observed in northwestern Albanel Township and till thickness in southeastern Poulin Township commonly exceeds 3 m. The ice-marginal delta in Viel Township and a similar feature in Hughson Township are more than 15 m thick. The measured height of the upper terrace in Sagard Township is 26 m above a local datum, but the underlying bedrock surface is irregular and this may not represent the true maximum local outwash thickness. Drift over the granitoid rocks in the northern and southeastern parts of the area is generally thin to absent.

ECONOMIC GEOLOGY

Supplies of sand and gravel are more than ample to supply local needs for the foreseeable future. The extensive outwash deposits of southwestern Sagard Township are more than 10 m thick and contain high percentages of pebble and cobble gravel. Gravel rock types are predominantly mechanically sound felsic plutonic rock and Huronian sandstone. Locally, oversized material may be a problem. Several pits in Sagard Township and one pit in Bouck Township are operated intermittantly on a demand basis. Boulders and oversized cobbles are a problem in the latter pit. Materials for forest access road construction can generally be found along or near the road route in most parts of the area.

The thickness and generally low level of humification of the peat in the large bog in Hembruff Township make it a possible source of horticultural peat moss. A fuller evaluation of the quality and quantity of the material is needed before any type of feasibility study could be attempted.

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27. Project Unit 90–52. Quaternary Geology of the Wawa Area, Northern Ontario

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INTRODUCTION

Quaternary geology mapping of the Wawa area continued to the northeast of previous work in the Hawk Junction map sheet (Morris 1990). Specifically, the northern half of the Manitowik Lake map sheet (NTS 42 C/1) and the southern half of the Franz map sheet (NTS 42 C/8) were completed. This area is bounded by longitudes 84°00'W and 84°30'W and latitudes 48°07'30"N and 48°22'30"N (Figure 1).

Surficial materials of the study area were previously delineated at a regional scale by Boissonneau (1966, 1968). An Engineering and Terrain geology map, at a scale of 1:100 000, was compiled by Gartner and McQuay (1979). The present study defines the distribution of surface materials and landforms and provides insights into their origin.

Glacial landforms were initially defined by remote-sensing imagery (black and white aerial photographs at scales of 1:15 480 and 1:50 000 as well as radar and Landsat imagery). Field work then defined materials related to landform. Material and landform origin was determined by examining their sedimentology, stratigraphy (through man-made and natural exposures) and distribution. Laboratory analysis of materials, including clast lithology, grain-size distribution, carbonate content and geochemistry will assist in separation and characterization of material units.

PHYSIOGRAPHY

The topography of the study area is described as moderate to undulating by Boissonneau (1966, 1968) and moderate to severely rugged by Gartner and McQuay (1979). Locally, the landscape can be quite level, although relief in some areas is over 198 m.

Many lakes and rivers in the western part of the study area (such as Goudreau, Pine, Cawdron and Cradle lakes) are aligned to the southwest. Lake orientation is controlled by bedrock structural features such as the Goudreau Lake and Cradle Lakes deformation zones (Arias and Heather 1987). Lake and river orientation elsewhere in the study area is controlled by other deformation zones (e.g., Emily Bay, Dog Lake and McKewen Lake deformation zones, Heather and Buck 1988).

BEDROCK GEOLOGY

Precambrian geology of the study area was previously mapped by Bruce (1940), Downes (1983), Riley (1971),

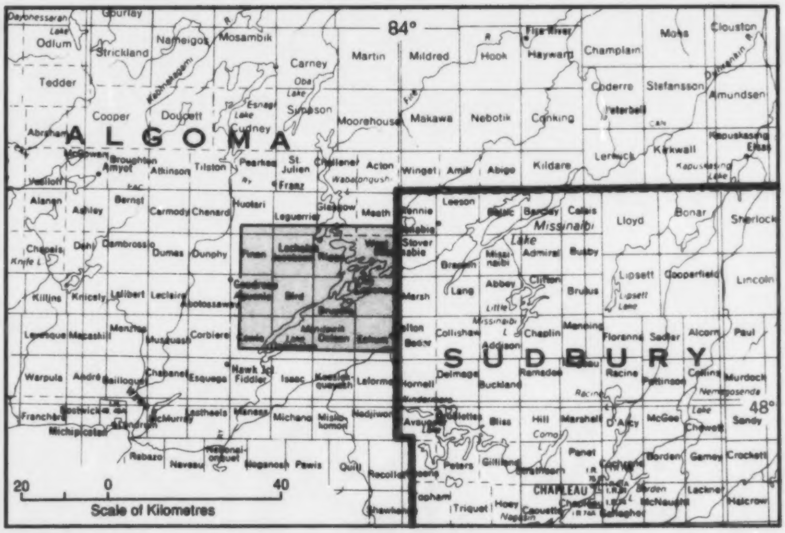
84°
ALGOMA
SUDBURY
48°
Odlum
Strickland
Nameigos
Mosambik
Carney
Martin
Mildred
Hook
Hayward
Champlain
Clouston
Tedder
Coderre
Stefansson
Amundsen
Cooper
Doucett
Simpson
Moorehouse
Makawa
Nebotik
Conking
Atkinson
Tilston
Pearkes
St. Julien
Franz
Acton
Winget
Abigo
Kildare
Kirkwall
Lloyd
Bonar
Sherlock
Alanen
Ashley
Bernst
Carmody
Chenard
Leeson
Missinaibi Lake
Lipsett
Cooperfield
Lincoln
Killins
Dunphy
Dumas
Collishaw
Chaplin
Paul
Wa...
Wardle
Delmage
Buckland
Racine
Murdock
Franchère
Michipicoten
Hawk Jct.
Fiddler
Isaac
Michano
Bliss
Hill
Marshall
McGee
Sandy
Rebazo
Naveau
Pawis
Peters
Borden
Gamey
Crockett
CHAPLEAU
Triquet
Halcrow
20
0
40
Scale of Kilometres

Figure 1. Location map of the Wawa area, scale 1:1 584 000.

Sage (1983, 1984, 1985, 1987) and Srivastava and Bennett (1978). Studies on gold mineralization were completed by Arias and Heather (1987), Heather and Arias (1987) and Heather and Buck (1988).

The study area is largely underlain by the eastern half of the Michipicoten greenstone belt. This belt contains Archean supracrustal rocks of the Wawa Subprovince of the Superior Province. There are four major metasedimentary and metavolcanic rock types recognized within this belt (Arias and Heather 1987; Heather and Arias 1987; Heather and Buck 1988; Goodwin 1962; Sage 1983, 1984, 1985, 1987; Srivastava and Bennett 1978). These are: 1) intermediate mafic metavolcanic rocks; 2) intermediate felsic metavolcanic rocks; 3) clastic metasedimentary rocks; and 4) chemical metasedimentary rocks. Granitic rocks comprise the remainder of the map area. Several felsic intrusive bodies occur within the supracrustal rocks (Arias and Heather 1987).

OBSERVATIONS ON THE GLACIAL GEOLOGY

The ground surface is largely controlled by bedrock topography. Exceptions to this are the areas east of Goudreau, at Dalton and at Fletcher Lake. At these locations, deposits of outwash and glaciolacustrine materials have subdued bedrock topography.

Striations, grooves and whalebacks are preserved on smooth and unweathered bedrock surfaces. Striations were observed throughout the map area. Whalebacks and grooves were less common. Striae orientation varies between 165° and 263° with a mean of 220°. The range of striae orientation is a function of the deflection of glacial flow around topographically higher areas. Cross-cutting striae were not observed.

Two types, or facies, of till were identified, the most common having a sandy to sandy-silt matrix. This till type is thin to nonexistent over bedrock highs and thickens slightly in bedrock depressions. This facies is found throughout the study area, although it occurs preferentially on the stoss (up-ice) side of bedrock knolls and ridges. This type of till is compact and massive and was deposited by lodgement processes. Material incorporation, transportation and deposition occurred at the base of the ice. Clast lithologies are predominantly of local origin.

The less common till type is more variable in matrix texture (silty sand to clayey silt). This till facies is usually greater than 1 m thick and is associated with recessional moraines. This till type is compact and consists of debris flow lenses. Debris transport occurred in the basal, englacial and supraglacial positions of the ice sheet and deposition was from both basal and supraglacial positions. Clast lithologies are derived both locally and regionally.

Deposits and features associated with deglaciation of the area include recessional moraines, eskers, meltwater channels, outwash and glaciolacustrine deposits. Recessional moraines are usually located at the heads of former meltwater channels. These moraines are subtle features a few metres in height and up to 0.5 km long. They consist of flowtills and large erratic boulders. Moraine distribution indicates ice margin retreat was to the north and northeast.

Ice initially forced meltwater to flow over the bedrock highland areas within well-defined meltwater channels. Ice retreat downslope of the bedrock highland areas caused the abandonment of the higher meltwater channels, as channels at lower elevations were uncovered. The distribution of the upstream ends or heads of these abandoned meltwater channels also defines ice marginal retreat to the north and northeast.

Outwash, consisting of sand and gravelly sand, was deposited within many meltwater channels. Some outwash deposits, such as those in the area around Goudreau Lake, are extensive and achieve thicknesses in excess of 6 m. Several well-defined eskers are partially buried by outwash. Eskers are as long as 3 km and are aligned to the southwest.

Deep-water sediments, such as laminated silts and clays and fine-grained sands, were deposited where glacial meltwater became ponded between the ice sheet and bedrock highlands. Such deposits were identified in the Dalton, Fletcher, Missinabie, Dog and Manitowik lake areas. A washing limit was identified in the Dog and Manitowik lake basins. Here, fine-grained material was washed from the till and deposited downslope by waves and currents of higher, postglacial lake. This washing action left a bouldery lag at the former lake level.

Several minor dune fields were defined northeast of Goudreau Lake. These dunes consist of fine-grained sand, which likely originated from a large outwash plain to the southwest. Dunes are parabolic and their orientation indicates paleowind direction was toward the northeast. Each dune field consists of up to three dunes which are as high as 9 m.

The elevations of terraces and paleo-lake levels throughout the study area were recorded using a Wallace and Tiernan altimeter. In addition, the elevations and slope of the terraces within the Magpie River Valley were surveyed. This survey revealed that there are more than the six major terraces originally described by Frey (1987) and Morris (1990).

ECONOMIC GEOLOGY

The majority of the potential aggregate resources within the study area occur within the well-defined meltwater channels as outwash sand and gravel or within glaciolacustrine basins as fine-grained sands. Several bulk samples of sand and gravel were taken and will be analyzed for grain size and examined to identify clast lithologies present. Grain-size analysis will define the grading curve and determine which aggregate products specifications the material meets.

Fine-grained materials (clay and silt) are used for dam construction and as landfill site liners. Laminated silts and clays are not widespread in the map area. They are restricted to Localsh Bay of Dog Lake and within several bays at the north end of Manitowik Lake.

Bulk till samples and pebbles were collected from a predetermined grid (2.5 by 2.5 km squares) superimposed over the map area. "B" horizon samples of till were collected at all sites. Samples of humus, "A" and "C" horizons were collected on a more limited basis. Geochemical analysis of these materials will provide background geochemical data for the area. In addition, two local pilot projects will provide information on the characteristics of till dispersal. The geochemical information derived from the regional and local till sampling programs, in conjunction with bedrock (Sage 1983, 1984, 1985, 1987) and geochemistry (Fortescue and Vida 1990) surveys, will provide information relevant to drift prospecting and environmental surveys.

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28. Project Unit 91–23. Soil Radon Gas Investigations in Southern Ontario

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INTRODUCTION

A regional scale soil radon gas survey (*see* Figure 1) was initiated by the Engineering and Terrain Geology Section of the Ontario Geological Survey in the autumn of 1991. The purpose of this survey is to determine the level of naturally occurring radon gas in soils (overburden). The survey is designed to examine the distribution and concentration of radon gas in a variety of geological settings. The database of soil radon gas concentrations that will be created by this project will be of value in assessing health dangers, building code standards and detailed, follow-up site testing.

TEST AREA SELECTION

In order to evaluate a number of different geological environments present in southern Ontario, four test areas were selected for monitoring. The areas selected have differing combinations of glacial materials and bedrock types. The areas are, however, characteristic of several other larger regions in southern Ontario. The areas, with a brief description of the geology, are as follows:

1. The western Essex County, Windsor area. In this region, a moderately thick sequence of clay-silt till and glaciolacustrine sediments overlie dolostone and limestone of the Hamilton and Dundee formations and Detroit River Group;
2. Kent and southern Lambton County, Wallaceburg area. Here, clayey silt till and glaciolacustrine sediments overlie shale of the Kettle Point Formation. Bedrock in the area is presumed to be faulted;
3. The Markham–Stouffville area. In this area, there exists a complex overburden sequence consisting of interbedded tills, glaciofluvial and glaciolacustrine materials. The bedrock in the area consists of black shale—the Collingwood Member of the Lindsay Formation—which occurs stratigraphically between carbonate rocks belonging to the lower part of the Lindsay Formation and the overlying Georgian Bay Formation;
4. The Belleville–Prince Edward County area. The surficial cover in this area is thin with the exception of some small, low-amplitude drumlins. Bedrock consists of Middle Ordovician limestones and dolostones of the Simcoe Group.

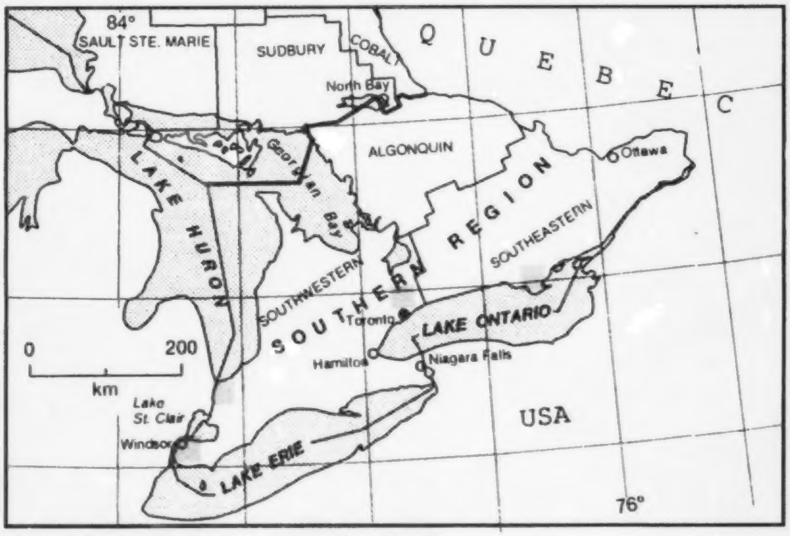

Figure 1. Location map of study area, scale 1:1 584 000.

RECOGNITION OF SAMPLING SUBENVIRONMENTS

Each of the 4 test areas listed above was assessed with regard to radon concentration of soil gas in specific subenvironments. The recognition of these is important in that the movement and concentration of radon within subenvironments may vary markedly. To properly interpret the result patterns and the geological controls on them, soil radon gas levels of all subenvironments must be adequately documented. The components which define these subenvironments are discussed under the 4 subheadings which follow.

Bedrock Geology

Differences in bedrock lithologies were taken into account as to their radioactive content. Black shales (Collingwood member of the Lindsay Formation and Kettle Point Formation) have very high radioactivity versus limestones and dolostones which have typically low radioactivity.

Local bedrock features, such as recognized faults or very limited, outcrop scale lithologies, were either avoided or treated separately during the survey. This depended on whether they represented a suitably sized target area.

Surficial Geology

The surficial geology, as the immediate media through which radon either passes or is generated *in situ*, was assessed with regard to the following:

1. composition—percentage and clast size of potentially radioactive components
2. permeability—the less permeable the material, the longer the transit times, enabling greater radon depletion, such that there is much less radon to be measured
3. thickness—a thicker vertical section will increase potential transit time allowing for increased radon decay and depletion, yet, at the same time, a thick section will allow much greater surface area for leaching with a potentially higher radon flux
4. soil development—the difference in soil development over each site was noted

Hydrogeology

An assessment was made of the rate and direction of groundwater flow. Vertical or lateral flow will displace radon from its source in either the bedrock or the surficial materials. The rate of flow displacement alone can be orders of magnitude greater than upward diffusion of radon gas.

Anthropogenic Modification

The activities of humans may either enhance or decrease soil permeability thereby locally altering the radon flux. Developments such as pipelines, large scale tile drainage areas or irrigation may greatly enhance the venting of naturally produced radon to the surface. Placement of detectors in such settings was avoided as it would bias the results.

The depletion, burial or addition of organic materials to the soil profile may act as a secondary trap for uranium, which can become a local radon source.

The repeated and/or excessive use of phosphate fertilizer will contribute significant amounts of contained uranium from phosphate (apatite). This outside source would release significant radon immediately adjacent to the detector. Obviously, heavily fertilized areas were avoided.

METHODOLOGY AND WORKPLAN

It must be understood that there may be pronounced variability in radon concentrations in soil gas from one sampling point to another, even within well defined geological environments. These variations reflect, among other factors, geology, weather changes, and anthropogenic disturbances. Proper interpretation of results requires careful observation and data recording at each sample site. Since glacial deposits cover most of the areas to be investigated, each area was inspected at the time of detector deployment. Other surficial and bedrock geology features were recorded, including the composition of tills and related glacial sediments, the nature of soils developed thereon and jointing in till and bedrock. These may influence radon concentrations.

Inspection was made of all sample sites to avoid placing detectors where radon concentrations may be influenced by human activity, such as buried service lines, field tile drainage systems, use of phosphate fertilizer, and so on. Service burial trenches disturb the soil and often are refilled with gravel and coarse aggregate, increasing permeability locally and resulting in greater radon flux. Field drainage tiles are good radon collectors, and elevated concentrations at discharges and at breaks in the line are common. Phosphate fertilizers usually contain from more than 10 to over 100 ppm uranium.

The Rad Elec Inc. E-perm radon gas measuring system was selected as the most applicable to the requirements of the survey. The radon detector is a charged teflon disk that carries a quasi-permanent electric charge. The static charge on the disk attracts charged ions which, one by one, reduce the charge on the disk. The surface voltage drop over a known time is a measure of time-integrated ionization during the period of exposure. The voltage drop value can be converted to radon concentration. The system includes the charged disks; an electrically conducting, plastic housing for the disk (electret); and a voltage reader that is used to measure the voltage on the electret before and after exposure. The voltage drop is recorded and converted by calculation to average radon concentration during the period of exposure.

The principle and application of this technology have been described by Kotrappa et al. (1990).

The detectors are also sensitive to gamma radiation and thoron progeny. Thoron is often present in soil gas at some level of concentration. Several sampling points in each subenvironment were checked for presence of thorium.

Gamma radiation measurements were made to obtain the contribution from this source to the apparent radon concentration. Special ion chambers were employed to generate the data necessary for this correction.

Approximately 40 sampling points were selected throughout each particular geologic subenvironment studied. Sampling density was variable from 1 per approximately 15 km² to 5 per approximately 1 km², depending upon the extent of the subenvironment and local conditions.

The 40 sampling points per subenvironment ensured enough determinations for statistical reliability, considering the inevitable loss of detectors and data due to animals, curious children, and other hazards.

The detectors were placed 15 to 30 cm below the surface of the soil in small-diameter excavations. The ion chamber was protected from flooding by an inverted container or radon-transparent waterproof envelope. The excavation was sealed using the soil removed from the hole which was then placed on a plastic sheet resting on the detector container. The plastic was to facilitate recovery of the detectors for short-term reading and final recovery.

In agricultural areas, the sampling points were chosen, as much as was possible, in undisturbed locations along township, county and provincial highway right-of-ways. In wooded areas, near-highway locations were chosen in undisturbed soil beside a prominent tree or other easily identified feature.

Detectors were read about 7 to 10 days after placement and reset for a longer period depending on the local soil gas radon concentration. Reading of detectors must be done before the sensing device is fully discharged. "Off-scale" readings are of limited statistical value. If radon concentrations were high and the sensor at a particular location overloaded, a new electret was installed and the measurement continued for an appropriate time.

Radon-concentration determinations are based on detecting and counting radon disintegration events, which is a statistical process. Radon sampling in soil is complicated by a wide range of influences. While it is the purpose of this survey to measure concentrations that are responding to geological influences, transient fluctuations due to changing weather conditions and other daily, monthly and seasonal factors can depress or accentuate short-term concentrations.

Therefore, when a precise determination of radon content at any location is required, long-term monitoring is necessary. Ideally, radon determinations should be done throughout an entire year to permit measurement of long-term average concentrations.

The data collected in this program will be properly representative of radon concentrations during the sampling period. The readings must be viewed, however, as having been affected by the natural, short term variables noted above.

Interpretation of results must be done with attention to details of the general and specific subenvironment from which they have been obtained.

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29. Project Unit 90–30. 1991 Drilling of Paleozoic Strata in the Lake Simcoe Area: Preliminary Results

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INTRODUCTION

In 1990, the Ontario Geological Survey began an investigation of the Paleozoic geology of the Lake Simcoe area, south-central Ontario (Armstrong 1990). The drilling component of this project was initiated in the spring of 1991 with the drilling of a deep hole, named OGS-91-1. Preliminary results of this investigation, in the form of the field description of this drillcore, are presented in this summary.

The Middle Ordovician carbonate strata of the Lake Simcoe area are a significant source of aggregate in the province. Parts of these carbonate strata contain beds which are alkali-reactive (i.e., deleterious in cement). A major focus of this project is to investigate the occurrence and distribution of these alkali-reactive beds.

Acquisition of subsurface samples by drilling plays a crucial role in this project. Drill core provides unweathered samples for both aggregate quality testing and stratigraphic information which will aid surface mapping. Located near the southern margin of the Lake Simcoe map area (Figure 1), drill hole OGS-91-1 was designed to intersect the most complete interval of Paleozoic stratigraphy on the eastern side of Lake Simcoe and thus provide a regional stratigraphic reference section. The average regional dip of Paleozoic strata in this area is approximately 4.76 m/km to the southwest (Liberty 1969).

LOCATION

Drill hole OGS-91-1 was located in an Ontario Ministry of Transportation wayside gravel pit on the north side of Highway 7, approximately 3.5 km west of the village of Manilla and approximately 23 km west of the town of Lindsay. The pit is located in Lot 19, Concession VIII, Brock Township, Regional Municipality of Durham. The location of the drill hole with respect to the Lake Simcoe project map area is shown in Figure 1.

PRELIMINARY DRILLING RESULTS

Drilling of OGS-91-1 commenced on March 13 and was completed on March 30, 1991. Delays in the drilling schedule were caused by difficulties encountered during cementing of the surface casing into bedrock. These difficulties may have

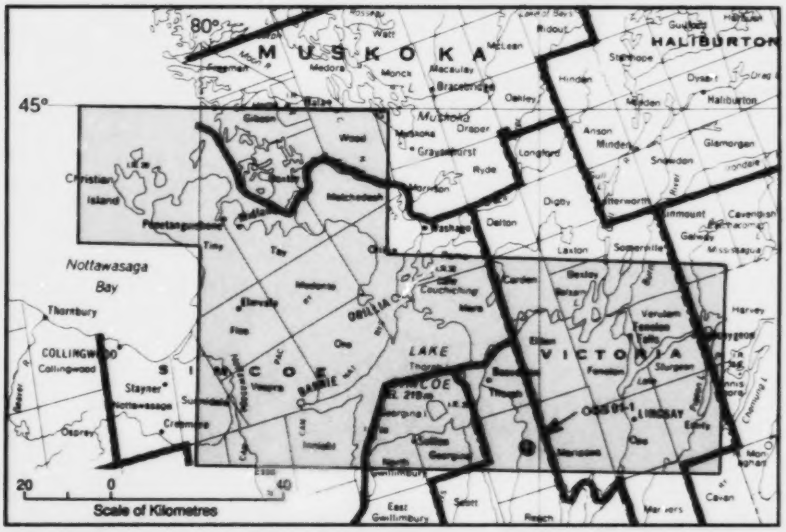

Figure 1. Location of Lake Simcoe map area (shaded) and drill hole OGS-91-1 (dot), scale 1:1 584 000.

been caused by groundwater flow in the porous, fractured, upper part of the bedrock.

The surveyed ground elevation at the drill site is 265.83 m above sea level. The hole was drilled to a total depth of 180.23 m, encountering 21.95 m of Quaternary drift, 149.26 m of Paleozoic strata, and 9.02 m of Precambrian basement. Surface casing (PW size) was drilled 30.5 cm into the bedrock surface. A smaller diameter casing (HW size) was drilled 30.5 m into bedrock and cemented in place. The Paleozoic and Precambrian intervals were cored with an HQ-size diamond bit, yielding almost continuous bedrock core, 63 cm in diameter. Upon completion of the hole and prior to plugging, the drill hole was geophysically logged with compensated-neutron, gamma-ray, compensated-density and caliper logs.

The Paleozoic interval encountered in OGS-91-1 consists of, in descending order, the Lindsay, Verulam, Bobcaygeon, Gull River and Shadow Lake formations. The following is a preliminary lithologic log of the drill hole based on observations of the drill core in the field.

Preliminary Lithologic Log of Drillhole OGS-91-1 (Manilla):

Depth (m)	Description
0 to 21.95	Quaternary drift: 0 to 9.0m—sand, gravel and cobbles; 9.0 to 21.94 m—clay and gravel
21.95 to 61.28	Lindsay Formation: dark grey, argillaceous, bioclastic, fine- to course-grained limestone, interbedded with thin, dark shale beds and minor dolostone. Subhorizontal (open?) fractures, more common in upper 30 m. Local nodular texture. Abundant hardgrounds and burrows.
61.28 to 109.50	Verulam Formation: interbedded dark grey-black, calcareous shale and richly bioclastic limestone with minor dolostone. Generally more shale rich than over- and underlying units. Echinoderms, brachiopods, hardgrounds and local secondary pyrite.
109.50 to 154.42	Bobcaygeon Formation: dark grey, very fine- to coarse-grained, bioclastic and micritic limestone with minor, thin shale interbeds and lesser dolostone. Micritic beds increase in abundance towards base of unit.
154.42 to 170.73	Gull River Formation: light-grey, tan, brown, and greenish-grey, micritic and argillaceous limestone and dolostone. Local evaporite mineral casts; well-developed fine lamination, stylolites and tight, vertical fractures.
170.73 to 171.21	Shadow Lake Formation: green and red, argillaceous, calcareous arkose. Local pyrite and clasts of weathered Precambrian material at the base.
171.21 to 180.23	Precambrian basement: red, white, and light-green, coarse-crystalline, granitic and quartzose gneiss. Uppermost 0.58 m is strongly weathered (i.e., regolith).

All of the contacts between the Paleozoic units encountered in this drill hole are conformable. The lithologic similarity of the Lindsay, Verulam and Bobcaygeon formations made the precise determination of formational contacts problematic. The Bobcaygeon, Gull River and Shadow Lake formations are more distinct lithologically, making the formational-contact picks more certain.

Preliminary analysis of the geophysical logs from this drill hole reveals little distinction among the units. The Verulam Formation interval exhibits a slightly higher gamma-ray profile, reflecting its higher shale content. The argillaceous interbeds in the Gull River Formation interval are reflected as distinct peaks in the gamma-ray response. The highest gamma-ray value was recorded for the argillaceous arkose of the Shadow Lake Formation. The Precambrian gneiss, at the bottom of the drill hole, is noticeably denser than the Paleozoic strata. A low-density zone above the base of the surface (HW) casing may indicate a washout in the fractured Lindsay Formation interval (a possible explanation for difficulties encountered in cementing the surface casing).

FUTURE WORK

The drill core from OGS-91-1 will be logged in detail and sampled for aggregate testing. Future drilling will be conducted to the north, closer to the outcrop belt. Areas with relatively poor outcrop exposure will be targeted as drill site locations in an effort to aid surface mapping. Detailed lithologic logs and geophysical logs of all the drill cores and holes drilled in this project will be released in open file format in the future.

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Geophysics/Geochemistry Programs

30. Summary of Activities 1991, Geophysics/Geochemistry Section

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GEOPHYSICS PROGRAM

This year, to celebrate the founding of the Ontario Bureau of Mines, a special volume on the Geology of Ontario is being produced. The Geophysics/Geochemistry Section's contribution to this volume is substantial. It includes the preparation of: 1) Bouguer gravity maps; 2) total field magnetic maps; 3) computer processed filtered gravity derivitive maps; and 4) magnetic derivitive maps. The maps are in sets of four which cover the entire province at a scale of 1:1 000 000.

During 1991, four airborne electromagnetic and magnetic surveys were released and all cover areas of the Province with high mineral potential. The maps represent approximately 53 875 line–kilometres of airborne geophysical observations distributed as follows: 1) Partridge River area (3985 line–kilometres); 2) Benny area (1590 line–kilometres); 3) Birch-Uchi-Confederation lakes area (26 310 line–kilometres); and 4) the Shebandowan area (21 990 line–kilometres). Complete sets of these maps are now available at each of two map scales.

A small research program, initiated in 1990 and designed to investigate bedrock topography and overburden thickness and stratigraphy, was continued in 1991. The 1991 activity included one siesmic line, which was shot near Newmarket a town 40 km north of Toronto. The aim of the siesmic investigation was to discover the location of a Laurentian Valley which is part of a proto-St. Lawrence drainage system.

GEOCHEMISTRY PROGRAM

The Section geochemical contribution to the Geology of Ontario volume is a chapter by the Research Geochemist reviewing highlights of geochemical mapping and environmental research since 1982.

By September 1991, a regional geochemical survey of the entire Batchawana greenstone belt had been completed. The survey was based on pre-*Ambrosia* lake sediment and lakewater samples. Geochemical data obtained from the lake sediments included the determination of levels of 35 elements and loss on ignition. Three parameters, pH, Ca and Mg, were determined in the lakewater samples.

By 1991 two geochemical map sheets (Trout Lake, and Hanes Lake) in a five-map series covering the entire Batchawana greenstone belt had been released. During 1991, two more maps (Pancake Lake and Montreal River) were published. In July and August 1991, samples were collected from the remaining map sheet (Cow River). All these surveys and maps have used exactly the same, standardized, geochemical mapping methodology. When completed, each of these five hard copy maps will be accompanied by a data diskette including the positional and geochemical data. The data is in digital format suitable for inputting directly into a Geographical Information System (GIS).

The design and planning of a mobile laboratory unit (MLU), which began in April 1990, continued during 1991. Design studies in 1991 focussed on: 1) the short and long term objectives of the MLU; 2) sample throughput requirements for servicing routine regional geochemical mapping projects; and 3) the need for uniform, high quality geochemical data, during a single, or multiyear, mapping program.

In May 1991, a small scale experiment was carried out using the POTMAP (POTentital MAPping) moving average technique applied to a study area within Batchawana regional geochemical map area. The aim was to discover a more effective method of displaying geochemical province patterns and geochemical gradients on regional geochemical maps. The preliminary experiment successfully demonstrated POTMAPS and they will be considered for inclusion as part of the standardized methodology for producing hard copy regional geochemical maps.

31. Project Unit 88–24. Single Master Bouguer Gravity Grid and Gravity Colour Maps for the Province of Ontario

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INTRODUCTION

A concise and state-of-the-art volume on the geology of Ontario is being prepared by the Ontario Geological Survey (OGS) to celebrate the centennial of the founding of the Ontario Bureau of Mines. The geophysical contribution consists of Bouguer gravity maps, total field aeromagnetic maps and computer-processed filtered gravity and magnetic derivative maps, all at a scale of 1:1 000 000. At this scale, the entire province of Ontario is represented on 4 map sheets.

The systematic regional gravity mapping of Ontario was initiated by the Dominion Observatory of Canada in 1947 (Innes 1960). Beginning in 1951 efforts were directed toward the establishment of a primary gravimetric network in Ontario. By 1964 uniform regional (albeit coarsely spaced) gravity coverage of most of Ontario, at a spacing of 10 to 15 km, had been achieved by the Dominion Observatory of Canada. The majority of the data acquired in northern Ontario were obtained through the use of light aircraft equipped with floats. The resulting Bouguer anomaly maps were published at a scale of 1:500 000 by the Earth Physics Branch of the Energy, Mines and Resources, Canada. Later surveys by the Earth Physics Branch, Ontario Geological Survey and the Atomic Energy Control Board, have resulted in significantly increased coverage in certain areas of the province.

The greenstone belts of Ontario are perceived to be regions having in the high economic mineral potential, but prospecting and geological mapping in these regions are hampered by inaccessibility and extensive areas of thick glacial overburden. Realizing the importance of regional gravity data, the Ontario Division of Mines initiated, in 1970, a systematic, detailed gravity survey program of the metavolcanic-metasedimentary belts of Ontario. Gravity surveys have been successfully used as an aid to geological mapping (Gupta and Ramani 1982) and in identifying areas that may be favourable zones for other detailed follow-up exploration (Gupta and Sutcliffe 1990).

The systematic detailed gravity surveys have helped in the determination of the deeper geological and geophysical characteristics of the Precambrian shield of Ontario (Gupta and Ramani 1980; Gupta and Grant 1985). Interpretation and modelling of the gravity field have constrained ideas about the third dimension of the metavolcanic-metasedimentary belts, contributing to a better understanding of their evolution (Gupta and Ramani 1982), and associated mineral deposits. Early detailed surveys in Ontario include Middleton (1976); Barlow et al. (1976); Gupta and Wadge 1978) and Gupta (1981).

State-of-the-art data processing and modern geophysical techniques have been applied to the existing gravity coverage of Ontario. The data is available, in digital form, from the National Gravity Data Base, maintained by the Geological Survey of Canada (GSC). A single master Bouguer gravity grid for the entire province of Ontario was created at a chosen uniform grid spacing of 1000 m. From this master grid, a set of 1:1 000 000 colour maps comprising the Bouguer gravity anomaly and its daughter products were generated, namely shaded-relief, vertical derivative grids. The vertical derivative maps are particularly useful for highlighting the near surface geology of the province.

The project was completed under contract by Paterson, Grant and Watson Limited of Toronto. Technical specifications and supervision was provided by the staff of the Ontario Geological Survey. Data integrity verification was provided by the staff of the Geophysical Data Centre of the GSC.

GRAVITY DATA

The Bouguer gravity map (Figure 1) and calculated first vertical derivative map (or vertical gravity gradient) of the Bouguer gravity (Figure 2) have been compiled from approximately 58 800 gravity stations. The Ontario Geological Survey has contributed over 23 000 gravity stations to this data base. The remaining stations were measured by the Earth Physics Branch and the Atomic Energy Control Board. The gravity measurements used in the compilation of the Bouguer gravity and vertical gravity gradient maps related daughter products are referred to the International Gravity Standardization Net 1971 (ISGN71) and the Geodetic Reference System 1967 (GRS67). Bouguer anomalies were calculated using a vertical gradient of 0.3086 mGal/m and a crustal density of 2.67 g/cm^3. The data were not terrain corrected except for 40 stations in the Sudbury area and 54 stations near Cornwall. In the current data base, the accuracy of the anomalies varies from ±0.5 mGal, for surveys completed by the Ontario Geological Survey, to ±2 mGals for the regional surveys and ±5 mGals for the shipborne surveys completed by the Earth Physics Branch.

DATA EDITING

The gravity data were provided in digital form as an XYZ data file, containing latitude, longitude and Bouguer gravity values in mGal by the Geophysical Data Centre. The data were converted from latitude and longitude coordinates to the Lambert Conformal Projection with a central meridian of 92°W, standard parallels of 49°N and 77°N with an origin of 0°N (equator) and 92°W. Using a minimum curvature gridding algorithm (Briggs 1974), the Bouguer gravity data were gridded to a 2000 m grid cell spacing for editing purposes. At the location of each input Bouguer gravity value of the XYZ file, a corresponding interpolated gridded Bouguer gravity value was extracted from the 2000 m grid file. The two values were then compared and the differences between the two data sets were entered into a third data set, known as the difference data set. This was later gridded to a 2000 m grid cell size, using the minimum curvature algorithm, with a 0.2 mGal tolerance of fit. Using an imaging workstation, colour images of the gridded difference data set and a plot of the gravity station locations were displayed concurrently to locate suspect bad values in the data set. Areas of poor fit to the input Bouguer gravity values were thus identified for further investigation. The sources of error-yielding poor fit were predominantly due to one of two factors; coarse gravity station sampling or an error in the original input Bouguer value.

Areas of high (large) Bouguer difference values (greater than 1 mGal) were evaluated using the Bouguer gravity maps published by the Earth Physics Branch and the Ontario Geological Survey. These areas were attributed to single point unsubstantiated anomalous values creating extreme localized gradients on the map or reduction using an incorrect station elevation. A total of 177 questionable gravity stations were deleted from the supplied XYZ file.

GRIDDING

Due to a large variation in the spacing of the gravity stations

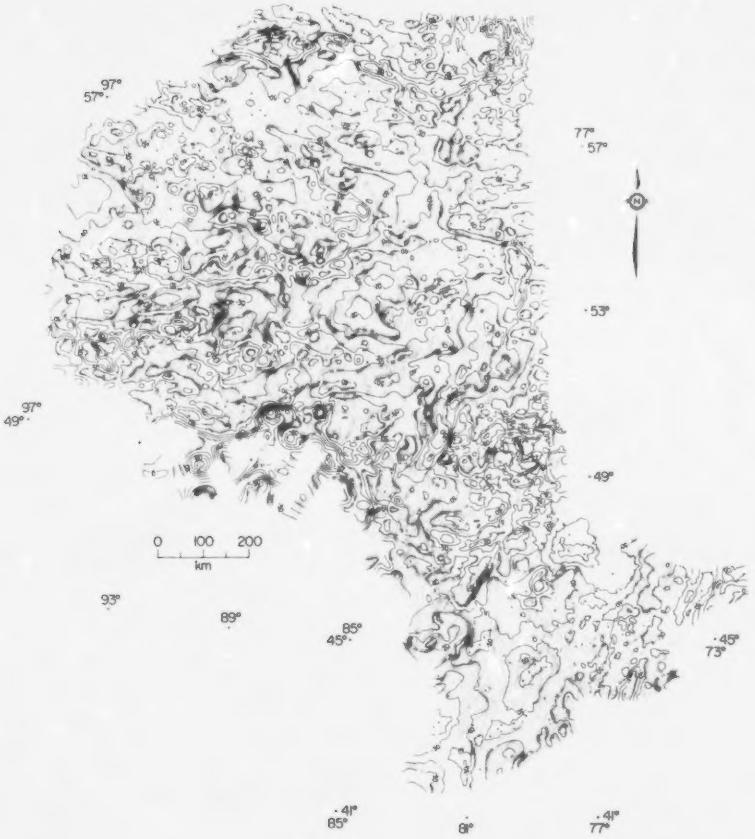

Figure 1. Bouguer gravity map of Ontario. Contour interval is 2 mGal.

(0.3 to 15 km) four test areas were examined to obtain the optimum gridding parameters. Each selected test area contained a mix of detailed and regional gravity stations. In addition, one of the areas also contained shipborne and ice surface data.

The four test areas were gridded at three different grid intervals (400 m, 1000 m and 2000 m) using the minimum curvature algorithm with tolerance of fit set at 0.01 mGal. The algorithm is a true two-dimensional gridding program that interpolates each grid cell from a minimum curvature surface that passes through all the input data. It produces a smoother-looking map than most other algorithms and is particularly well suited to use with random-type input data. The minimum curvature gridding method is the method of choice by the GSC and OGS for treating their aeromagnetic and gravity data and was required for the creation of the master grid. Colour raster images of the gridded Bouguer gravity field were displayed on the workstation to compare and check for aliasing, anomaly resolution and examination of how well the original input data was honoured by the gridding process. It was determined that the 1000 m grid cell size exhibited the minimum aliasing and the maximum resolution.

THE VERTICAL GRAVITY GRADIENT MAP

The rationale for computing a vertical gradient map (Gupta and Sutcliffe 1990; Gupta and Grant 1985) or a second vertical derivative (Gupta and Ramani 1982) is that anomalously dense rocks occurring near the ground surface produce much stronger gradient effects that those which lie at depth. However, it should be noted that the amplitudes of the Bouguer gravity anomalies that are caused by shallow and weak sources may be considerably smaller than those due to larger, deeply buried sources. The vertical derivative map thus enhances the weak, near-surface anomalies.

Fourier spectrum analysis techniques were applied to aid in the selection of the parameters for the calculation of the first vertical derivative (1VD) of the Bouguer gravity. When the 1VD operator was applied to the Bouguer gravity, with no additional filtering, aliasing of the signal was obvious in areas of low sample density. In order to overcome the aliasing present in the 1VD grid, a low pass cosine roll-off filter was

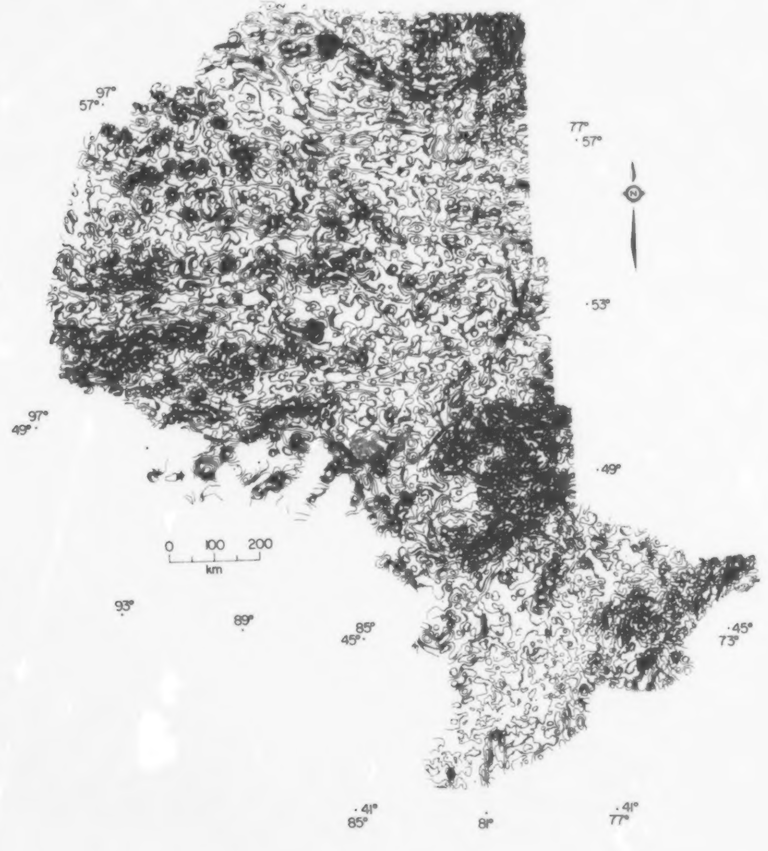

Figure 2. Vertical gravity gradient map. Contour interval is 0.2 mGal/km.

designed and applied to the Bouguer gravity grid in the Fourier domain prior to application of the 1VD operator. Numerous tests were conducted with varied cosine filter parameters and analysis of the pre- and post-filtering spectrums in order to obtain the optimum filter coefficients. The final, low-pass, cosine roll-off filter of the fourth order, with roll-off wavelengths commencing at 7000 m and ending 5000 m, was applied to the data to remove the sharp roll-off at the higher frequency end of the filter. The combined effect of the final cosine roll-off and 1VD operator is illustrated in Figure 3. The first vertical derivative map in the space domain was obtained by taking the inverse Fourier transform of the filtered frequency domain data. The resulting vertical derivative map exhibits a balance between low aliasing and high resolution.

The vertical derivative map is used primarily to locate vertical to subvertical boundaries between rock units of contrasting densities. The zero contour of the vertical derivative anomalies helps to outline approximate boundaries of the vertical lithological sources. The vertical derivative map is, therefore, useful for mapping near-surface structures, such as faults and folds.

SHADING

In an effort to enhance low-amplitude, short wavelength, near surface anomalies, a full-colour shaded relief image of the vertical gradient of the Bouguer gravity field was produced. An optimum shading vector was obtained for each map sheet such that the gravity trends to be enhanced were normal to the direction of illumination. In a colour map, the full range of the colour scale represents all wavelengths present in the data, but often lacks the definition in the shorter wavelengths in areas of high dynamic range. A shaded relief map attempts to provide additional resolution of the short wavelength features in such situations. To this end, a 61-colour scale was designed with grey-scale shading superimposed on the colour image to enhance the shorter wavelength features and provide more texture in the overall appearance of the vertical gravity gradient map.

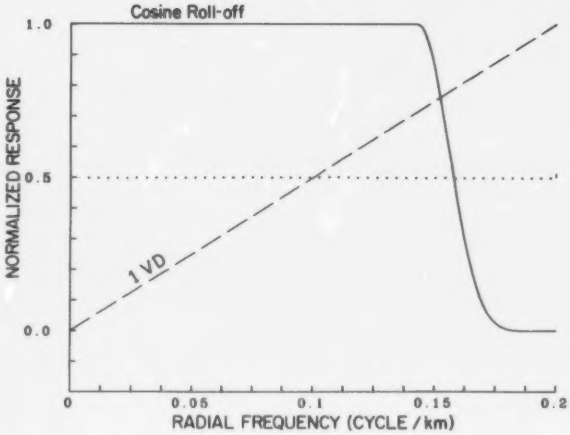

Figure 3. Radial frequency-domain response of the first vertical derivative filter.

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32. Project Unit 89–44. Bedrock Topography in the Regional Municipality of York

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INTRODUCTION

One hundred years ago Spencer (1891) proposed that a buried bedrock valley extended from the east shore of Georgian Bay, southwest of Lake Simcoe, to Lake Ontario in the Toronto region. This valley, which Spencer termed the Laurentian River System, comprised part of a proto-St. Lawrence River drainage system.

This system is of great interest because the location of the bedrock valley influenced the distribution and type of deposits of pre-Late Wisconsinan glaciations. These valleys are now infilled with thick sequences of glacial drift that may indicate paleoenvironmental conditions at the time of deposition. Hydrogeologists are keen to learn more about the Laurentian buried bedrock valley because gravel sequences near its base are currently being exploited as municipal aquifers, for example, in the Regional Municipality of York. Consequently, there is a need to know the exact location of the Laurentian Valley.

Until now, Ministry of Environment water-well records have been used to compile bedrock topography maps, which are then used to delineate possible locations of the Laurentian Valley. Unfortunately, the quantity and quality of water-well data has resulted in many different interpretations of bedrock topography and the precise location of the Laurentian Valley is still uncertain. The goal of this project was to use geophysical techniques to delineate the Laurentian buried bedrock valley.

LOCATION

Work was centred around the town of Newmarket, about 40 km north of Toronto. Water-well data was compiled for most of the Regional Municipality of York, and the southeast corner of Simcoe County (Figure 1). This region was chosen because it is highly developed, resulting in a fairly dense scattering of water well data. Development is not sufficiently advanced, however, to hinder seismic surveying.

The first phase of the project was compiling water-well data and plotting a bedrock topography map. Ministry of Environment records (1983 to current) were examined and any holes intersecting bedrock were plotted. These data were then contoured (using SURFER), resulting in the map depicted in Figure 2. The contours thin out in the northeast and northwest corners of this map because there is very little data in these regions. Some general trends are apparent on

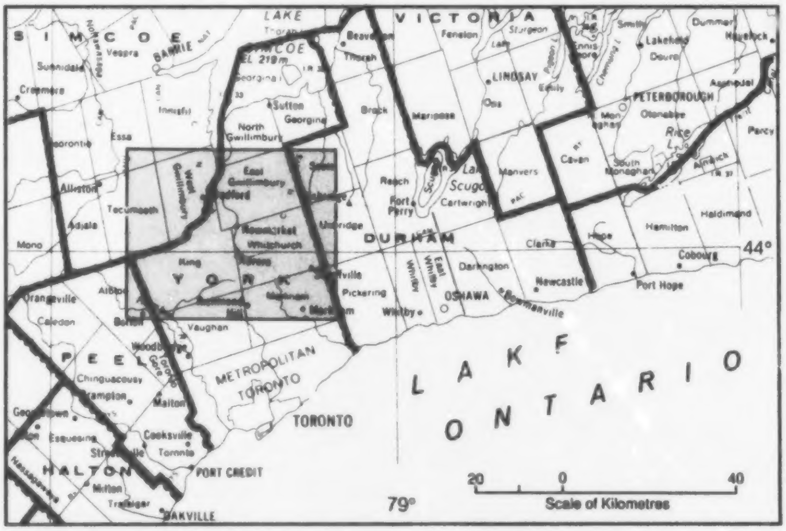
SIMCOE
LAKE SIMCOE
EL 219m
BARRIE
Vespra
Sunnidale
Creemore
Innisfil
Essa
Tecumseth
Alliston
Adjala
Mono
Orangeville
Caledon
Albion
Bolton
North Gwillimbury
Georgina
Sutton
West Gwillimbury
East Gwillimbury
Bradford
Newmarket
Whitchurch
King
Aurora
YORK
Vaughan
Richmond Hill
Markham
Uxbridge
Pickering
Thorah
Beaverton
Brock
Reach
Port Perry
Scugog
Lake Scugog
Cartwright
DURHAM
Whitby
East Whitby
OSHAWA
Darlington
Clarke
Newcastle
Bowmanville
VICTORIA
Fenelon
Sturgeon Lake
LINDSAY
Emily
Ops
Mariposa
Manvers
Cavan
Smith
Lakefield
Douro
Dummer
Havelock
Asphodel
PETERBOROUGH
Otonabee
Rice Lake
South Monaghan
Alnwick
Percy
Haldimand
Hamilton
Hope
Cobourg
Port Hope
44°
PEEL
Chinguacousy
Brampton
Malton
Woodbridge
Georgetown
Esquesing
Streetsville
Cooksville
Toronto
METROPOLITAN TORONTO
TORONTO
PORT CREDIT
HALTON
Milton
Trafalgar
OAKVILLE
LAKE ONTARIO
79°
20
0
40
Scale of Kilometres

Figure 1. Location map, scale 1:1 584 000. Shaded area is depicted in Figure 2.

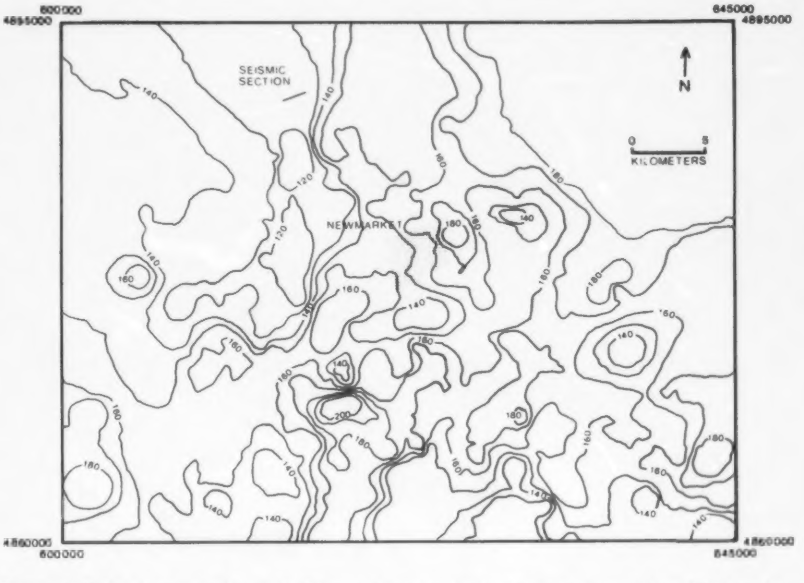

Figure 2. Bedrock topography of the Newmarket region derived from watre-well data. Numbers in the corners are Universal Transverse Mercator (UTM) co-ordinates. Contour interval is 10 m. Elevations are in metres above sea level.

the map. One is a bedrock depression (with basal elevations of about 120 m above sea level) which extends southward just west of Newmarket. This depression appears to swing east about 7 km south of Newmarket, but it is no longer a continuous feature at this point.

Examination of Figure 2 suggested that the most likely location for the Laurentian Valley would be the southerly trending depression west of Newmarket. To test this hypothesis it was decided to shoot a seismic line somewhere across this feature. To conduct a shallow reflection seismic survey required: 1) a fairly flat road (because surface topography will affect the resultant seismic record); 2) little traffic (because this adds noise to the seismic records); and 3) wet ditches (to ensure good coupling of the shot and geophone to the earth). The best road matching these conditions in the area is located just north of Bradford in West Gwillimbury Township.

SEISMIC SURVEY

A 1.6 km line of seismic data recorded every 3 m was collected along the tenth line road about 3 km north of Bradford. Gwyn and White (1973) have identified the surficial material at the eastern end of the line as sandy lacustrine sediment. The central portion of the line has silty sand Newmarket Till at the surface, while the western end is underlaid by the clayey silt Kettleby Till. The line has about 35 m relief, taking the form of a gradual rise from the east to the west.

Multichannel records along the line indicated that 33 m would be the optimum offset for the conditions encountered. Each channel was recorded for 204 ms, at a sampling rate of 0.1 ms/sample. Recording was done on the Geometrics 2401 seismograph, using 100 Hz geophones. A 200 to 1000 Hz analog filter was applied during recording to eliminate noise in the extreme high and low ends of the spectrum. A conventional 12-gauge shotgun source (Pullen and MacAulay 1987) was used in a hole about 1 m deep.

All the shots were collected in one file, statically corrected and then digitally filtered (from 200 to 600 Hz) to produce the section displayed in Figure 3.

DISCUSSION

Two prominent reflectors can be seen on the section depicted in Figure 3. The upper reflector occurs at 40 ms on the eastern portion of the section and dips to about 75 ms at the western edge of the section. The lower reflector dips from 85 ms at the eastern edge to 160 ms at the western edge. This lower reflector is interpreted as the bedrock-overburden interface.

Calculation of average velocities requires flat-lying reflectors. Since the two prominent reflectors on this section are dipping for most of the line, they were not suitable for velocity analysis. However an average of velocity estimates obtained from fairly flat-lying portions indicates an average velocity of 1800 ms^{-1} down to a depth of 160 ms. This is a reasonable velocity value for water saturated unconsolidated material. Based on this value, the lower reflector represents a horizon occurring at 77 m depth at the eastern end and dips down to 144 m below the surface at the western end of the survey line. The seismic depth estimates are in good agreement with water-well data for the area. The nearest borehole to reach bedrock lies about 2 km south of the survey line. Here bedrock was encountered at a depth of 136 m.

There are no deep boreholes along the survey line that can be used to identify reflectors within the overburden. The borehole 2 km south of the line did, however, encounter a layer of hard stony clay (possibly till) overlain by soft clay (possibly lacustrine sediments) at a depth of 67 m. Using an average velocity of 1800 ms^{-1} this corresponds to a two-way travel time of 74 ms. This corresponds to the upper reflector mentioned previously.

The geometry of the lower reflector suggests that the seismic line may have been shot over the eastern flank of a valley. If this seismic line does intersect the Laurentian Valley, then a continuation of the line should show bedrock rising up to the west. Unfortunately, time constraints prevented us from extending the line in this direction.

The reflectors above the lower reflector are not flat lying. If this section did depict the eastern half of a valley, the infilling sediments should be horizontal. Since these units parallel the lower reflector, the section may simply depict bedrock with a mantle of overburden dipping to the west. If this is the case a 67 m drop over 1.6 km represents a dip of 2.3°.

Another explanation for the geometry of the reflectors may be surface topography. Surface relief is flat for the eastern quarter of the line, where the reflectors are also flat lying. Surface topography rises to the west at the same location as the reflectors begin to dip down. The dip of the reflectors may therefore be artificial, induced by lining up the first arrivals of each trace. As the survey progressed uphill, there would be more material overlying the reflector, which would then appear deeper. If the traces were aligned so that the reflectors were flat lying, then the first arrivals would appear like a hill.

The possibility that the lower reflector is a multiple of the upper reflector should be mentioned. Multiples occur on seismic records when energy from the shot is trapped within a layer and two reflections are recorded from the same horizon. The most common type of multiple occurs when there is a strong impedance contrast between two horizons, resulting in a majority of the energy being reflected from that interface. Since energy from the multiple has travelled twice as far as the primary reflection, the travel time is twice as long. On a seismic section, then, the multiple will always appear twice as late as the primary reflection.

In the western portion of our section the upper reflector occurs at about 75 ms, while the lower reflector occurs at about 150 ms. This "double-time" relationship between the upper and lower reflectors can be observed across the entire record. However closer inspection reveals that the lower reflector does not always arrive twice as late as the upper event. The geometry of the two events is also different. In the central portion of the section the upper reflector is fairly flat lying, while the lower reflector drops about 20 ms. Given this, it is unlikely that the lower event represents a multiple from the upper reflector.

CONCLUSIONS

Bedrock in the Regional Municipality of York has approximately 80 m of relief. While the northern portion of the Newmarket region shows southerly trending bedrock valleys, these trends shift to easterly just south of Newmarket. No continuous structures are evident over the whole map sheet, however, the quality and spatial distribution of the water-well data is not ideal. The lack of any distinct bedrock valleys on Figure 2 may simply be due to the fact that no deep water wells were located over such structures.

Shallow reflection seismic surveying does offer a detailed view of bedrock topography and overburden stratigraphy.

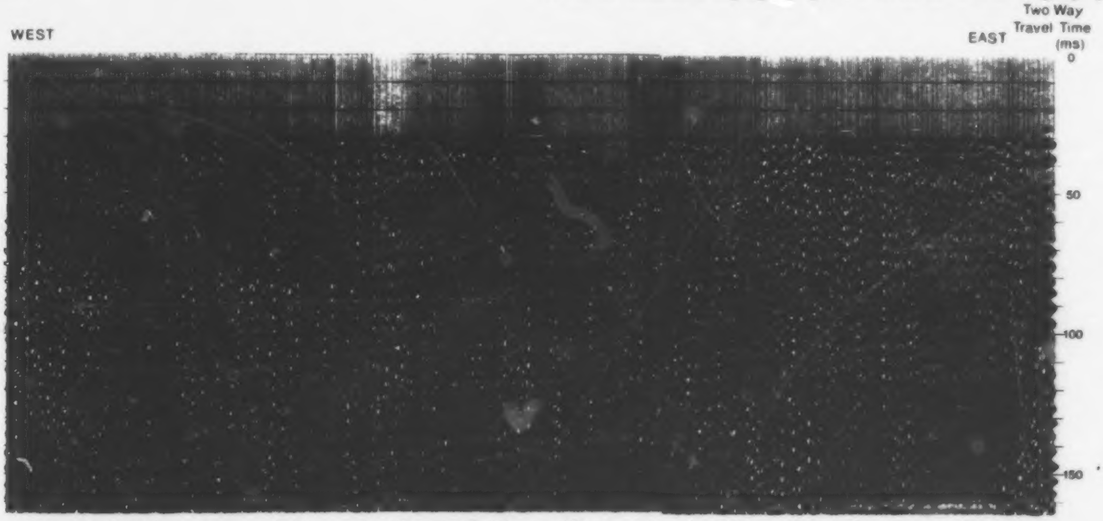

Figure 3. Seismic section recorded just north of Bradford in West Gwillimbury Township. Trace spacing is 3 m. Factors affecting the seismic record are road traffic and ground moisture (required to ensure good coupling of the shot and geophones to the earth).

Our section shows bedrock lying at a depth of 77 m to the east and 144 m to the west. The westward thickening wedge of overburden shows numerous internal reflectors with 1 prominent event at 40 ms in the east and 75 ms in the west.

The complimentary use of water-well and seismic data can provide much useful information. The former can be used to depict general trends and large structures, while the latter can be used to give a detailed picture in areas that were identified as interesting from the broad picture. Water-well data can then be used to assign lithological units to the reflecting events observed on the seismic section.

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33. Project Unit 90–24. Regional Geochemical Mapping in the Batchawana Greenstone Belt: The Cow River Project

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INTRODUCTION

In August 1991, a regional lake sediment and lakewater geochemical mapping survey was completed in the Cow River area, about 70 km northeast of Sault Ste. Marie (*see* Figure 1). The Cow River survey covered an 875 km^2 area in the northeast part of the Batchawana greestone belt, approximately 100 km east of Lake Superior.

The Cow River regional geochemical survey is the last of five surveys (Fortescue and Vida 1989, 1990, 1991a and 1991b) covering the entire Batchawana greenstone belt. The average sample density for the greenstone belt survey is 1 sample per 1.19 km^2.

Each of the maps in this geochemical series will provide the following:

1. a coloured, 1: 50 000 scale map of the area with a preliminary interpretation of geochemical patterns in the marginal notes, a standard set of tables, digitized data, and graphs
2. a data base diskette(s) which includes positional and geochemical data suitable for downloading into a geoscience Geographical Information System (GIS).

OBJECTIVES

The objective of the Batchawana regional geochemical map series is to provide a uniform geochemical data base/information of the entire greenstone belt for mineral exploration and environmental geochemistry. All data base file formats will be suitable for downloading directly into a GIS.

When completed, the Batchawana series will be the first Ontario Geological Survey (OGS) regional geochemical data base covering an entire greenstone belt. Using a GIS approach, this data base may now be directly integrated with the recently completed OGS regional geophysical database in the same area (Ontario Geological Survey 1990).

As part of a data processing experiment, portions of the OGS regional geological map of the Batchawana belt have been digitized recently (Fortescue, Vida, Rencz and Wright, this volume). This experiment will eventually include a GIS approach to the interpretation of the geoscience of the Batchawana area involving geology, geophysics, geochemistry and remote sensing.

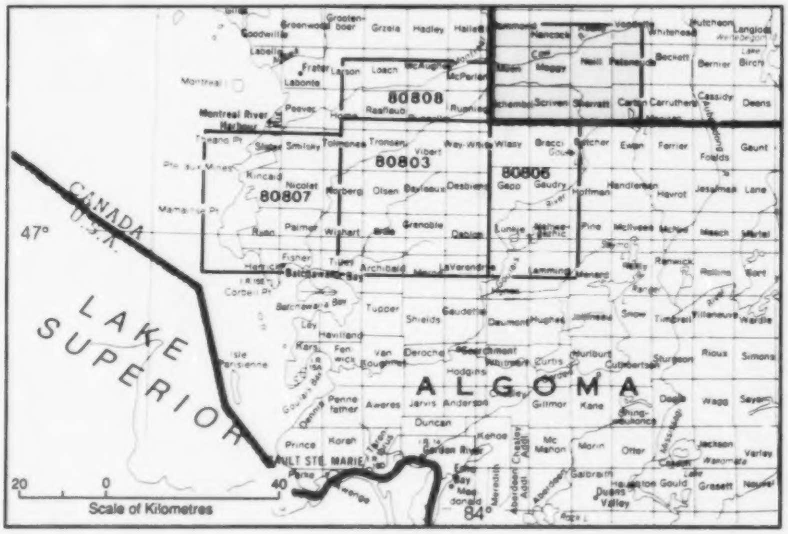

Figure 1. Location map of study area., scale 1:1 584 000.

THE COW RIVER GEOCHEMICAL SURVEY

The aims of the survey are to apply a previously standardized methodology to:

1. complete a regional-level, mineral resource appraisal, geochemical survey of a 35 km by 25 km area in the eastern part of the Batchawana greenstone belt
2. determine the concentrations of 35 elements (Ag, Al, As, Au, Ba, Be, Bi, Br, Ca, Cd, Co, Cr, Cu, Fe, Hf, K, La, Lu, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sc, Sr, Ta, Th, Ti, U, V, W, and Zn), plus LOI, in all the Cow River lake sediment core samples
3. determine the pH, Ca and Mg levels in the Cow River lakewater samples
4. prepare a regional geochemical map of the Cow River area using a standardized format
5. describe important geochemical patterns for selected parameters in the Cow River geochemical data base
6. identify geochemical targets of possible importance in mineral exploration and/or of environmental significance in the Cow river area
7. format the geochemical data bases in a form suitable for direct input into a GIS.

Location

Figure 2 shows the location of the Cow River map area and the other four geochemical maps in the series. The Cow river map includes: 1) all, or most of, Schembri, Scriven, Sherratt, Moen, Moggy and Neill townships, 2) at least half of Hammond, Hancock, Kosny, Vondette, Patenaude and Carton townships, and 3) minor portions of Wlasy, Running, McParland, and Hallett townships.

Geology

The geology of the Batchawana greenstone belt (including the Cow River area) has been described recently in a comprehensive report by Grunsky (1991). Aspects of the geology in the Cow River area were also described by Grunsky (1981, 1982, 1983, and 1984) as a part of the Batchawana Synoptic Project. Figure 2 (from Grunsky, 1991) is a generalized geological map of the area which also delineates the boundaries of all five regional geochemical maps in the Batchawana greenstone belt.

Rocks in the Cow River map area include the northeast portion of the Archean Batchawana greenstone belt, bounded by granitic terranes to the north and the south (*see* Figure 2). The greenstone belt is composed of metavolcanic and metasedimentary rocks which have been structurally deformed, metamorphosed, hydrothermally altered, faulted and intruded by felsic intrusive, and massive felsic intrusive rocks. At a later stage, rocks in the entire map area were intruded by mafic intrusive rocks (gabbro) and numerous diabase dikes.

Grunsky (1983) divided the rocks of the Batchawana greenstone belt and its surrounding granitic terranes into four major lithotectonic domains. Three of these domains occur in the Cow River area, and they are the Ramsey gneiss, the Chapleau gneiss and the Batchawana metavolcanics.

The Chapleau gneiss domain is found in the northwest portion of the Cow River area, and the Ramsey gneiss domain rocks occur in the north-central, east and southeast parts of the map area. The eastern metavolcanic domain, which is the youngest volcanic cycle in the Batchawana greenstone belt, occurs in the central part of the Cow River area. Locally, these rocks range in composition from mafic to felsic. The bedrock geology in the Cow River is further complicated by the late intrusion of massive felsic rocks (e.g. the Troy Lake stock and the Schembri Township stock) into the Ramsey Gneiss Domain and the eastern mafic metavolcanic rocks (Corfu and Grunsky 1987).

Quaternary Geology

Roed and Hallett (1980) described the Quaternary geology of the Cow Lake area north of latitude 47°00'N. In this area, the direction of the last glacial advance was to the southwest. During deglaciation, till was deposited as thick (1 to 7 m) and extensive ground moraines. Meltwaters from the retreating glaciers laid down sand and gravel as outwash plains, eskers and kames. This further complicated the Quaternary stratigraphy in the Cow River area, where relief is locally moderate to high, with low areas in outwash plains and organic terrains.

The bedrock in the Batchawana metavolcanic and Ramsey gneiss domains (*see* Figures 2 and 3) is almost completely covered by thick Quaternary deposits. This may complicate the delineation and interpretation of geochemical anomalies and geochemical provinces in the Cow River area.

Forest cover in the Cow River map area is a patchwork of Boreal forest and mixed forest growth. Extensive logging has occurred over the entire map area.

Field Work

In August 1991, an OGS crew of four visited 1053 lakes and ponds within an 875 km^2 area. From these sample points, a total of 939 lake sediment and 1053 lakewater samples were collected. The 939 samples included 858 pre-*Ambrosia*, 33 mixed-*Ambrosia* and 48 post-*Ambrosia* lake sediment core samples. It was not possible to obtain lake sediment from the remaining 114 sample points, because of hard lake bottoms and other difficulties.

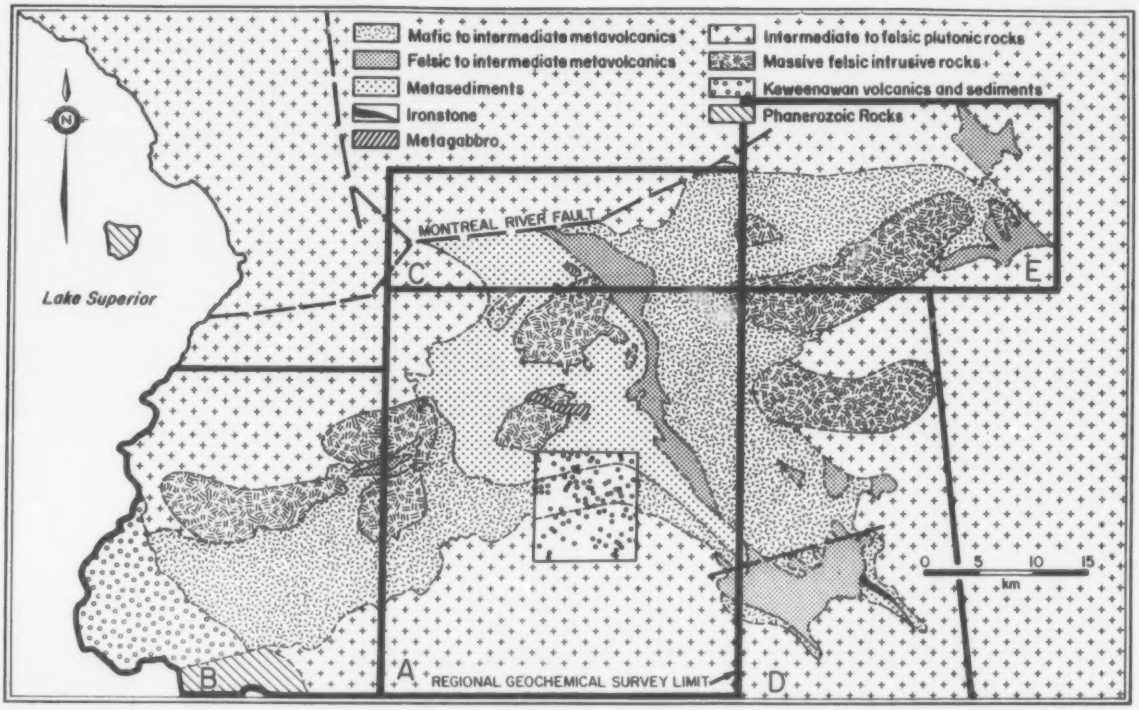
Mafic to intermediate metavolcanics
Felsic to intermediate metavolcanics
Metasediments
Ironstone
Metagabbro
Intermediate to felsic plutonic rocks
Massive felsic intrusive rocks
Keweenawan volcanics and sediments
Phanerozoic Rocks
N
Lake Superior
MONTREAL RIVER FAULT
A
B
C
D
E
REGIONAL GEOCHEMICAL SURVEY LIMIT
0
5
10
15
km

Figure 2. Generalized geological map (from Grunsky 1991) of the Batchawana synoptic project delineating the limits of the five regional geochemical surveys and, as an inset, the sample density for lake sediments. The letters within the sampled area refer to thee individual regional geochemical map sheets as follows: A—Trout Lake area, B—Pancake Lake area, C—Montreal River area, D—Hanes Lake area and E—Cow River area.

Surface lakewaters were collected from all shallow ponds in the Cow River area. Composite water samples (representing a depth of 0 to 5 m) were collected (with a 5 m Tygon tube sampler) from all lakes and ponds deeper than 6 m.

Lake sediments were collected using a gravity core sampler developed by the OGS as described by Fortescue (1988). After collection, each lake sediment core sample was extruded into a whirl-pak bag, on the helicopter float, as described by Fortescue (1988). The sample collection rate averaged between 55 and 75 samples per day during the Cow River project.

In base camp, the pH of cooled, 250 ml lakewater samples was determined within 24 hours of collection using a Hanna Instruments (HI) 8418 pH metre. Levels of Ca and Mg in the water samples will be determined at the OGS Geoscience Laboratories in Toronto.

Quality control (QC) of the lake sediment sample processing methodologies is to be based on the analysis of data from: 1) the analysis of subsamples of a homogenized lake sediment collected from Borden Lake, near Chapleau; and 2) replicated analyses of Geological Survey of Canada (GSC) lake sediment standards LKSD-1 to LKSD-4. Prior to leaving the field, wet QC samples were sequenced randomly into the batch of unknown lake sediment samples.

Sampling Density

A total of 3398 pre-*Ambrosia* lake sediment cores and water samples have been collected from the 4050 km^2 area covered, by the five regional geochemical maps of the Batchawna greenstone belt. Variations in the average sample density within the five geochemical surveys in the greenstone belt are evident from Table 1. For purposes of comparison, the average sample density data for traditional "reconnaissance" lake sediment geochemical surveys conducted by the Geological Survey of Canada (Friske 1985) and "low density" geochemical mapping based on "overbank" sampling (Ottersen et al. 1989) in Norway are also included in Table 1. The feasibility of "overbank" sampling in Ontario was investigated at a single site by Fortescue and Bolviken (1990).

OGS Field Sampling Methodology Improvements

TULMAR CREW JACKETS

In 1989, canoe floatation vests were used by the OGS staff collecting lake sediment cores on a helicopter float. Because of the wide range of movements required on the float, it was discovered that floatation vests were: 1) impractical to wear due to the restricted movement caused by the vests, and 2) too hot for comfort in the summer.

Table 1. A comparison of regional geochemical sample densities.

OGS Batchawana survey (average)	one sample per 1.19 km^2
OGS Cow River survey 1991	one sample per 0.93 km^2
OGS Pancake Lake survey 1988	one sample per 3.55 km^2
OGS Montreal River survey 1988	one sample per 1.39 km^2
OGS Hanes Lake survey 1989	one sample per 1.03 km^2
OGS Trout Lake survey 1987/1988	one sample per 1.30 km^2
GSC Reconnaissance geochemical survey	one sample per 13.00 km^2
Norwegian overbank geochemical survey	one sample per 500.00 km^2

In 1991, the OGS substituted inflatable Tulmar crew jackets, identical to the type worn by the helicopter pilot in the 1989 lake sediment survey. The experiment was successful in: 1) decreasing awkward and restricted movements on the float, 2) increasing safety by reducing operator fatigue, and 3) safely increasing the rate of sampling.

COMPUTERS IN THE HELICOPTER

Prior to 1991, all field observations for lake sediment core sample sites were written by OGS crews in a notebook and transferred into a computer in base camp each evening. Both procedures are slow and may result in recording errors. Field notes may also vary slightly from navigator to navigator during the same survey. This variation may cause problems during data processing and data interpretation.

In 1991, in an attempt to solve this problem, a series of experiments were conducted using a Hewlitt Packard HP 95LX "Palmtop" Computer. The "palmtop" was convenient and practical to use in the field because it operates on two AA batteries and includes a cell battery as a backup. An HP 82241A adapter was used to the conserve battery power of the "palmtop" while in base camp.

While navigating the helicopter during the Cow River project, recorded data were entered directly into the resident Lotus 1-2-3 program in the HP 95LX palmtop. Distinct advantages of this method include: 1) the convenient size of the "palmtop", 2) the 512 K memory facility, 3) the resident programs, and 4) a resident Lotus 1-2-3 program which can be setup for direct inputing of field data. Data files within the "palmtop" can be simultaneously stored in the 512 K resident memory and in a 512 K RAM card. This card is used as an extended memory and a data diskette. Each evening, an entire day's field notes is downloaded from the "palmtop" into a personal computer (PC), using the HP F1001A Connectivity Pack.

Experience with the "palmtop" indicated that field logging of the data is very convenient and accelerates the data collection process in the helicopter. Almost immediately after sample collection, rapid comparisons are possible using field data and initial data interpretation.

The next step planned after the implementation of the "palmtop" computer for regional geochemical mapping is the addition of a global positioning device (GPS) in the helicopter. The employment of both instruments will ensure that location maps of sampling sites and other data can be updated on a daily basis. Similarly, when the OGS Mobile Laboratory Unit (MLU) (*see* Fortescue, this volume) is in full operation, data from the MLU and these two instruments can be combined to produce updated geochemical maps within 72 hours of sample collection.

THE USE OF SEMI-AUTOMATED PH METERS

Prior to 1991, it was difficult to synchronize the determination of the pH of lakewater samples with the rate of sampling. As an experiment in 1991, two Hanna Instruments (HI) 8418 pH meters were obtained for use in the field sampling program. The advantage of this instrument is that its calibration and operation is a quick and uncomplicated, one and/or two step operation(s). With the HI 8418 instrument, sixty pH determinations can be completed in less than half a day. This is double the productivity of the pH instrument used prior to 1991.

The HI 8418 instrument is also capable of printing and/or directly downloading into a computer the: 1) sample number, 2) pH, 3) water conductivity, 4) water temperature, 5) date, and 6) time. Therefore, two copies of pH calculation data sets are available for data file backups; a paper printout and a computer file of the downloaded pH values. Using a memory resident program, the sample number, date, and time could be changed with each pH measured.

The HI 8418 instrument was found to be reliable and quick in a field base laboratory and reduce transfer errors in data collection. This computerized pH meter enabled a plot of a map showing pH values for the entire Cow River area to be completed within 24 hours after the last sample was collected (Figure 3).

Summary

The three inovations in the lake sediment sampling methodology (the Tulmar crew jackets, "palmtop" computer and semi-automated pH meter) were tested in the Cow River project. All were successful and contributed significantly to an increase in the effectiveness and safety of the program.

RESULTS

A plot of the pH patterns in the Cow River area shows patterns similar to previous regional geochemical map sheets (Fortescue and Vida, 1989, 1990, 1991a and 1991b). High pH patterns delineating areas of thick and continuous ground moraines, outwash plains and valley trains were found in the adjacent Montreal River and Hanes Lake map areas. These patterns persist into the Cow River area (see Figure 3).

Figure 3a shows all lakewater sample sites in the Cow River area where pH was measured, within a 24 hour period,

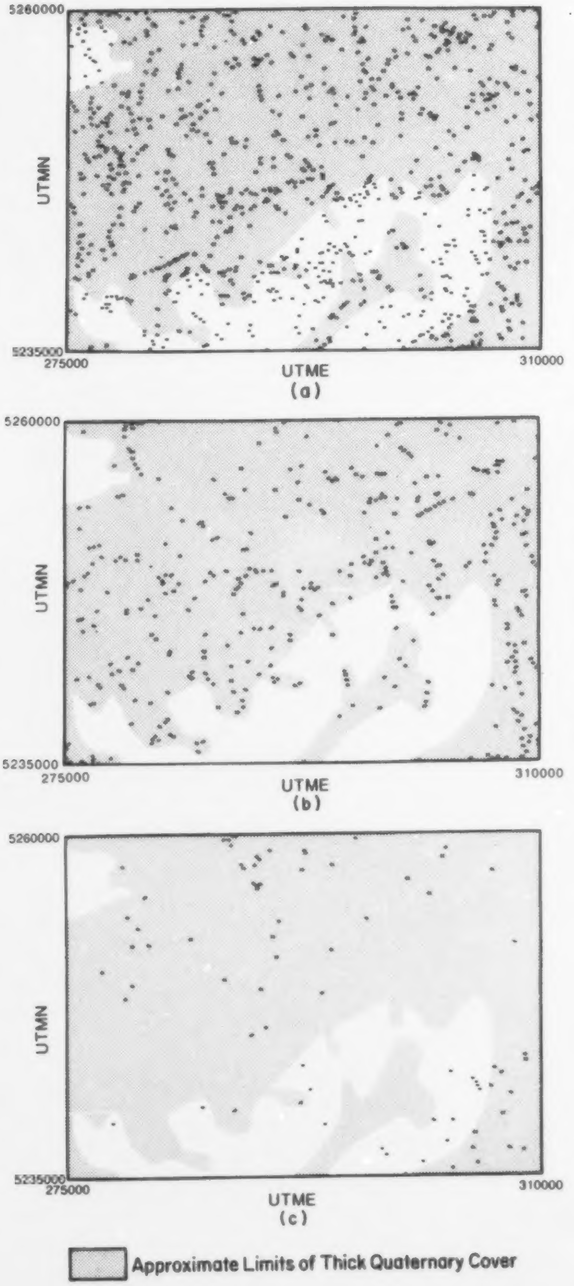

Figure 3. Regional map pattern of pH values in the Cow River area with the approximate limits of the Quaternary geology delineated. (a) all sample sites in the Cow river area; (b) all sample sites with pH values greater than, or equal, to 7.0; and (c) all sample sites with pH values less than, or equal, to 6.0.

over the duration of the project. The large complex of ground moraines and outwash plains in the Cow River area are delineated in Figure 3b (pH greater than or equal to 7.0). Lakewaters in the Cow River area with relatively low pH (i.e. less than or equal to 6.0) occur in areas of thin or no Quaternary cover (*see* Figure 3c).

The processing of the pH data demonstrates how geochemical map patterns can be updated on a day to day basis during a regional geochemical mapping program. In the case of pH patterns, the locations of lakes of particular environmental interest can then be selected for special study during a field sampling program. For example, during the Cow River sampling program, a small number of anoxic lakes were discovered which could have been studied for environmental purposes, using methods described by Dickman and Fortescue (1991), before the end of the field work.

PRESENT STATUS

The Cow River area geochemical survey was planned during the early summer of 1991. Fieldwork was completed during late July and August 1991, and was largely the responsibility of Elizabeth A. Vida.

At the time of writing, the water samples had been delivered to the OGS Geoscience Laboratories for Ca and Mg determinations, and all lake sediment samples were stored in a cold room pending delivery to a Contractor for element and LOI determinations. The Cow River regional geochemical map and data base diskette(s) are planned for release by OGS before the end of 1992.

ACKNOWLEDGMENTS

Assisting with the fieldwork were Chris Fouts and Andrew Corbiere. Air Muskoka, under contract to the OGS, supplied the Bell 206 helicopter, with Dave McCullagh and Gary Tihivsky as pilots.

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34. Project Unit 89–43. Regional Geochemical Mapping in the Michipicoten Greenstone Belt: The Murray Lake Project

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INTRODUCTION

In mid-June 1989, a regional lake sediment and water geochemical mapping survey was completed in the Murray Lake area, approximately 65 km north east of Wawa (*see* Figure 1). In mid-September 1991 an area approximately 90 km northeast of Wawa (north of the 1989 Murray Lake survey) and an area 55 km northeast of Wawa (south of the 1989 Murray Lake survey) were sampled usign the same methodology. The complete Murray Lake survey covers 920 km^2 area in the east portion of the Michipicoten greenstone belt (*see* Figure 2).

The Murray Lake survey is the second regional geochemical survey conducted within the Michipicoten greenstone belt (Fortescue and Vida 1990a). The average sample density of the complete area surveyed is 1 sample per 1.07 km^2.

Both maps in this geochemical series will provide the following:

1. A coloured, 1:50 000 scale map of the area with a preliminary interpretation of geochemical patterns in the marginal notes, a standard set of tables, digitized data, and graphs.
2. A data base diskette(s) which includes positional and geochemical data suitable for downloading into a Geoscience geographical information system (GIS).

OBJECTIVES

The objective of the Michipicoten regional geochemical map series is to provide a uniform geochemical data base/information of the entire greenstone belt for mineral exploration and environmental geochemistry. All data base file formats will be suitable for downloading directly into a GIS.

When completed, the Michipicoten series will be the second Ontario Geological Survey (OGS) regional geochemical data base to be located in a greenstone belt.

THE MURRAY LAKE GEOCHEMICAL SURVEY

The aims of the survey are to apply a previously standardized methodology to achieve the following:

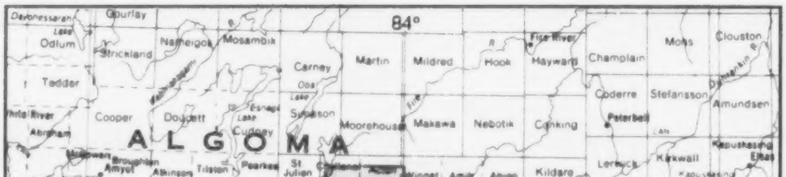

Figure 1. Location Map of the Murray Lake area and the Herman Lake area regional geochemical maps, scale 1:1 584 000.

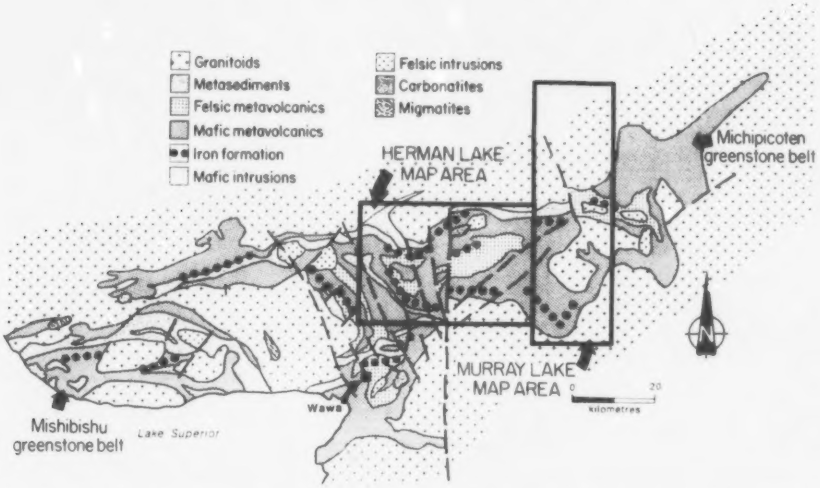

Figure 2. Generalized geological map of the Michipicoten synoptic project delineating the boundaries of the 2 regional geochemical surveys.

1. complete a regional-level, mineral resource appraisal, geochemical survey of a 46 km by 20 km area in the east part of the Michipicoten greenstone belt
2. determine the concentrations of 35 elements (Ag, Al, As, Au, Ba, Be, Bi, Br, Ca, Cd, Co, Cr, Cu, Fe, Hf, K, La, Lu, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sc, Sr, Ta, Th, Ti, U, V, W, and Zn), plus LOI, in the Murray Lake lake sediment core samples
3. determine the pH, Ca and Mg levels in the Murray Lake lake water samples
4. prepare a regional geochemical map of the Murray Lake area using a standardized format
5. describe geochemical patterns for selected parameters in the Murray Lake geochemical data base
6. identify geochemical targets of possible importance in mineral exploration and/or of environmental significance in the Murray Lake area
7. format the geochemical data bases in a form suitable for direct input into a GIS.

Location

Figure 2 shows the location of the complete Murray Lake map area in relation to the adjacent (published) Herman Lake geochemical map. The 1991 Murray Lake map area includes: 1) all, or most, of Glasgow and Meath townships; 2) at least half of Challener, Acton, Dolson and Echum townships; and 3) partial portions of Keesickquayash and Laforme townships. The 1989 Murray Lake map area includes: 1) all, or most of, Riggs, west Missanabie, Bruyere, and Copenace townships; 2) at least half of Dolson and Echum townships; and 3) partial portions of Glasgow and Meath townships.

Geology

Precambrian supercrustal rocks of the Wawa area are known as the Michipicoten and Mishibishu greenstone belt (*see* Figure 2). The Murray Lake map area is located near the east end of the Michipicoten greenstone belt and is bounded to the north and south by granitic terranes (*see* Figure 2). Two volcanic cycles are found in the map area: 1) a 2750 Ma felsic volcanic, and 2) 2700 Ma mafic volcanic. Both cycles trend to the northeast across the map area. Iron formations in the Murray Lake area are located within: 1) the felsic metavolcanics in the northeast, and 2) the mafic metavolcanics in the south. Both the stratigraphy and structural geology of the Murray Lake area are complex. Rock alteration zones and a large number of diabase dikes also complicate the geology.

Primary references should be consulted for further geological information in the area (Goodwin 1962; Turek et al 1982, 1984 and 1988; Sage 1984, 1985, 1987a, 1987b and 1989; Arias and Heather 1987; Heather and Arias 1987; Heather and Buck 1988).

Quaternary Geology

Gartner and McQuay (1979) described the Quaternary geology of the Murray Lake area from latitudes 48°00'N to 48°30'N and from longitudes 84°00'W to 85°00'W. In this area, the direction of the last glacial advance was to the south-southwest. The advancing ice deposited a stony, sandy till as thin (1 m thick) recessional ground moraines. No evidence exists to support stationary ice fronts during deglaciation in the area, so these ground moraines represent local terminations of the ice front (Boissonneau 1968). During deglaciation, meltwaters from the retreating glaciers laid down sand and gravel as outwash plains, valley trains, eskers and kames. On slopes and in valleys, glaciofluvial sediments are occassionally

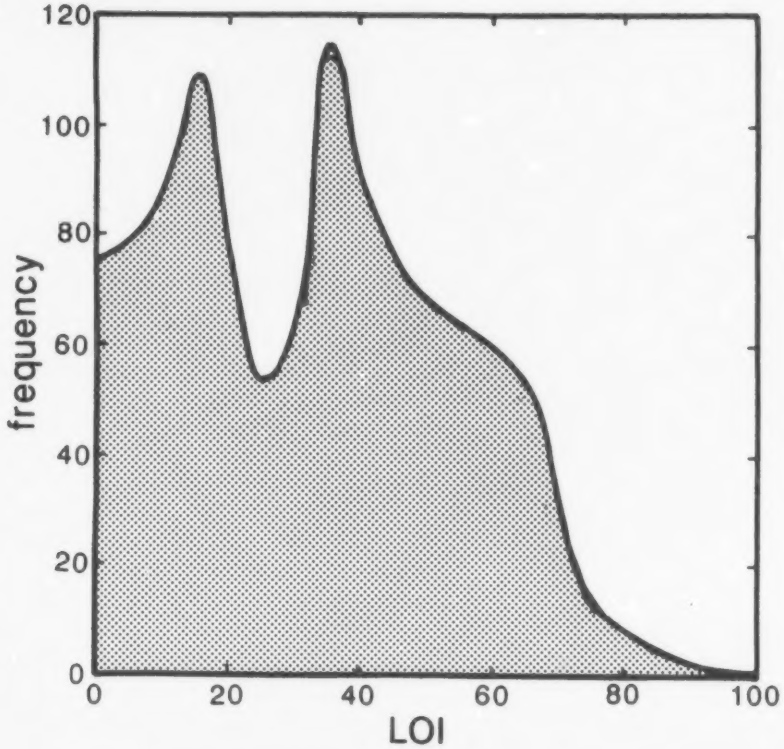

Figure 3. Frequency plot of the 1989 Murray Lake lake sediment LOI data. Frequency is expressed as actual numbers of sediment samples and the LOI values are in percent.

greater than or equal to 5 m in thickness. Local relief is moderate to high with minor low areas in river valleys.

Because Quaternary cover in the Murray Lake area is thin and discontinuous, regional geochemical mapping and interpretation of geochemical anomalies and geochemical provinces are favourable. However, the collection of organic lake sediments in some parts of the area was restricted by large lakes with sandy bottoms.

Forest cover in the Murray Lake map area is of mixed forest growth. Logging is evident over the entire map area.

Table 1. A comparison of regional geochemical sample densities.

OGS Michipicoten survey (average)	one sample per 1.07 km^2
OGS Murray Lake survey 1989	one sample per 1.30 km^2
OGS Murray Lake survey 1991	one sample per 1.23 km^2
OGS Batchawana survey (average)	one sample per 1.19 km^2
OGS Cow River survey 1991	one sample per 0.93 km^2
OGS Pancake Lake survey 1988	one sample per 3.55 km^2
OGS Montreal River survey 1988	one sample per 1.39 km^2
OGS Hanes Lake survey 1989	one sample per 1.03 km^2
OGS Trout Lake survey 1987/1988	one sample per 1.30 km^2
GSC Reconnaissance geochemical survey	one sample per 13.00 km^2
Norwegian overbank geochemical survey	one sample per 500.00 km^2

Field Work

In the orginal 1989 Murray Lake Survey, a total of 487 pre-*Ambrosia* lake sediments and lake water samples were collected (Fortescue, et al. 1989). In the September 1991 survey, a total of 493 pre-*Ambrosia* lake sediments and lake water samples were collected by another OGS crew. Sampling in both surveys were conducted using a Bell 206 helicopter equipped with floats. A total of 980 pre-*Ambrosia* lake sediment and lake water samples were collected from the entire 920 km^2 Murray Lake area. Details of the methodology employed to obtain the geochemical data are described in Fortescue, Vida and Wadge (this volume). The sample collection rate was an average of 50 samples per day during the Murray Lake project. Three innovations were introduced to the regional geochemical sampling methodology in 1991, which are fully described in Fortescue, Vida and Wadge (this volume).

Sampling Density

A total of 1722 pre-*Ambrosia* lake sediment cores and water samples have been collected from the 1920 km^2 area covered by the two regional geochemical maps of the Michipicoten greenstone belt. Variations in the average sample density within the 2 geochemical surveys in the greenstone belt are evident from Table 1. For purposes of comparison, the average sample density data for traditional "reconnaissance" lake sediment geochemical surveys conducted by the Geological Survey of Canada (Friske 1985), the five regioanl geochemical maps in the Batchawana greenstone belt (Fortescue and Vida, 1989, 1990b, 1991a and 1991b) and "low density" geochemical mapping based on "overbank" sampling (Ottersen et al. 1989) in Norway are listed in Table 1.

RESULTS

Both the 1989 and the 1991 Murray Lake geochemical surveys included samples composed of: 1) pre-*Ambrosia* sediment, 2) mixed pre- and/or post-*Ambrosia* sediment, 3) post-*Ambrosia* sediment, and 4) sand. A frequency plot of the 1989 LOI Murray Lake data shows a bimodal frequency distribution (Figure 3). Organic and sandy lake bottoms almost certainly account for this bimodal distribution. The interpretation of regional patterns in the Murray Lake area geochemical data is likely to be complicated by this major variation in lake sediment sample types.

PRESENT STATUS

The 1991 Murray Lake area geochemical survey was planned the during the late summer of 1991 and the fieldwork was carried out in late September and early October. At the time of writing, the water samples had been delivered to the OGS Geoscience Laboratories for Ca and Mg determinations and the lake sediment samples were stored in a cold room pending delivery to a Contractor for chemical analysis. The Murray Lake regional geochemical map and data base diskette(s) are planned for release by the OGS during 1992.

ACKNOWLEDGMENTS

Assisting with the fieldwork were Chris Fouts and Graeme Lillie. Air Muskoka, under contract to the OGS, supplied the Bell 206 helicopter, with Keith Harley as the pilot.

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35. Project Unit 90–25. Progress in Planning a Mobile Laboratory Unit (MLU) to Support Geochemical Mapping and Environmental Geochemistry

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INTRODUCTION

Fortescue (1990) provided preliminary information on plans for a Mobile Laboratory Unit (MLU) designed to service Ontario Gelogical Survey (OGS) geochemical mapping projects in the field. Since then, the MLU project has continued and arrangements are now underway to build the MLU in the near future. The MLU will be a component of the Ministry of Northern Development and Mines Sudbury Relocation Project. This article describes some information pertinent to the planning of the MLU which was carried out during 1991.

OBJECTIVES OF THE MOBILE LABORATORY UNIT

Objectives of the MLU project were revised during 1991 and now read as follows:

1. To provide a self contained, mobile, laboratory facility to carry out sample pre-treatment and chemical analysis in support of all kinds of OGS geochemical mapping and environmental programs.
2. To further the Ministry of Northern Development and Mines goal of satisfying client demands for high quality geochemical data, maps, and environmental reports in a timely manner.
3. To ensure, within season and season to season, standardization of geochemical data obtained for Branch mineral resource appraisal and environmental geochemistry projects.
4. To guarantee that a preliminary interpretation of chemical data obtained from a mapping project can occur before project fieldwork ends.

Point 4 represents a important advance in OGS geochemical mapping methodology. For example, during mineral resource appraisal projects, rapid data feedback of chemical data from the MLU will enable verification of geochemical anomalies to be completed during project fieldwork. This will save the cost of mounting separate "geochemical anomaly verification programs" after sampling, but before printing, OGS geochemical maps.

The rapid turnaround of samples due to the use of the MLU will also be important during the research and development of new geochemical field mapping methodologies. These include the development of methodologies designed for mineral resource appraisal in areas of Ontario where, for example, lake sediments cannot be used.

Quick turnaround of geochemical samples will also enable the OGS to respond quickly and positively to certain environmental emergencies. For example, the MLU can be dispatched to areas where water supplies have been contaminated by trace elements derived from a sudden destabilization of a mine tailings dump, and quickly determine the extent of damage.

AN ENLARGEMENT OF THE OGS GEOCHEMICAL MAPPING MLU CONCEPT

During 1991, the long term concept of the OGS MLU was broadened and deepened to include the possibility of a second laboratory vehicle in the future. The second vehicle would contain a modern Inductively Coupled Plasma Mass Spectrograph (ICP-MS) of advanced design. Instruments of this type are desirable for geochemical mapping as they are capable of determining, quantitatively, most elements in the Periodic Table at the very low limits often required in geochemical mapping. In addition, a modern ICP-MS has a wide dynamic range and can be setup to have semi-automated operation for a throughput of 100 samples per day on waters without complex pre-treatment procedures.

In the long term, the experience obtained with the MLU described here should facilitate the establishment of a similar second laboratory. The geochemical maps produced by both MLUs working in tandem would be some of the most advanced of their type in the world.

THE INITIAL OPERATION OF THE MLU

Initially, the MLU will operate in the field during the summer months servicing lake sediment and water based regional geochemical mapping of the type described elsewhere in this volume (Fortescue, Vida and Wadge, this volume; Vida et al., this volume).

When configured for this type of fieldwork, the MLU will pre-process 100 samples of water and 100 samples of lake sediment per day. Plans for the chemical analysis to be carried out on the pre-processed samples have not yet been finalized.

When the MLU is not required for fieldwork the laboratory will carry out research on methods development. To do this, it will be operated in its special garage within the Sudbury OGS facility. Eventually, methods will be developed for pre-processing and chemical analysis of humus, plants, peat, and other materials required for future OGS geochemical mapping programs.

MLU SAMPLE THROUGHPUT FOR LAKE SEDIMENT/LAKEWATER REGIONAL GEOCHEMISTRY

To support lake sediment and lakewater regional geochemical mapping, it is estimated that the MLU will need to process around 100 samples of lakewater and lake sediment per day for a period of 10 to 15 days. The purpose of this section is to describe how these numbers were chosen.

Each of batch of 100 samples would normally include 70 unknown samples plus 30 quality control (QC) and blank samples. The QC samples would include: 1) replicates of unknown samples; 2) replicates of an OGS-QC standard (mixed from locally derived samples); 3) international QC standards (e.g. the Geological Survey of Canada LKSD series for lake sediments); and 4) reagent blanks.

Since February 1988, the OGS has collected lakewater and lake sediment samples to support a series of seven regional geochemical maps. This experience provided detailed information on the rate at which lake sediment core and lakewater samples are collected using a helicopter and a sampling crew of two OGS staff. Daily sample collection rates for waters and sediments in three of the surveys are listed in Table 1. The objective of two of these surveys, (Hanes Lake and Cow River, *see* Table 1) was mineral resource appraisal. For this reason they involved the collection of pre-*Ambrosia* lake sediment cores and lakewaters from each sample site. The third survey, at Magpie River, was carried out for mineral resource appraisal and, experimentally, environmental geochemistry. To achieve these objectives both pre- and post-*Ambrosia*, lake sediment core samples were collected at each sample site.

Table 1 shows that the duration of the three geochemical survey programs varied between a minimum of 11 and a maximum of 20 working days. The shorter period was required to collect 410 lakewater and 810 lake sediment samples from 405 sample sites in the Magpie River area. This compares with twenty working days required to collect 1059 pairs of water and lake sediment samples from the Hanes Lake area (*see* Table 1).

Let us suppose that the MLU had been used to service the three projects. Let us also suppose that the planned sample throughput of 100 samples per day had been maintained in the MLU throughout all three projects. Then, in the Hanes Lake area, (where an average of 53 pairs of samples were collected each day), the 100 sample throughput of the MLU would have been more than adequate to process every sample on 16, out of the 20, days.

In the Cow River example (*see* Table 1) 60, or more, sample pairs per day were collected each day over a over a 17 day period. In this case the maximum MLU throughput of 100 samples per day would have been fully utilized for 11 out of the 17 days. In the Magpie River example, two separate lake sediment core samples and one lakewater sample were obtained from each sample site. In this case, an average of 72 lake sediment samples and 36 lake water samples were collected per day during the 11 day period. If the MLU had been used for this project it would have been required to work at full capacity during the entire 11 day period. In this case, geochemical data from only half of the lake sediment samples (i.e the pre-*Ambrosia*) would have been required immediately for mineral resource appraisal purposes. For this reason, in this project, the MLU could have processed all pre-*Ambrosia* samples first and the post-*Ambrosia* samples later on before the MLU moved from the field area.

In summary, 'sampling time' data obtained from three regional geochemical surveys, has demonstrated that a planned throughput of 100 samples per day for the MLU is realistic. At this sample throughput rate the MLU could service analytical needs of current OGS regional geochemical mapping/sampling programs based on the use of a single helicopter. If two helicopters were used for sampling, the MLU would be required to work 24 hour days to satisfy a demand for chemical data from day to day.

THE IMPORTANCE OF STANDARDIZED CHEMICAL DATA FOR REGIONAL GEOCHEMICAL MAPPING

Chemical data for use in regional geochemical mapping must be reliable for all elements from day to day, month to month and year to year. This is because slight variations in pre-processing and/or chemical analysis of geochemical samples may produce slight changes in chemical data. These may later seriously affect regional geochemical map patterns formed during data processing. For this reason, an important aim of the MLU is to provide OGS geochemical mapping programs with reliable, high quality, multielement chemical data.

Table 1. Sampling rates for 3 regional geochemical surveys. Notes in brackets () explain low sampling numbers.

Day	HANES LAKE (1990) Pre-*Ambrosia* (only)	COW RIVER (1991) Pre-*Ambrosia* (only)	MAGPIE RIVER (1988) Pre- + post-*Ambrosia*
1	46	10 (orientation)	39 + 39 = 78
2	24 (fog)	53	51 + 51 = 102
3	62	47	46 + 46 = 92
4	76	69	27 + 27 = 54
5	65	69	20 + 20 = 40
6	68	65	42 + 42 = 84
7	59	66	41 + 41 = 82
8	65	63	41 + 41 = 82
9	16 (fog)	69	52 + 52 = 104
10	18	60	37 + 37 = 72
11	40	65	6 + 6 = 12
12	75	50	—
13	72	61	—
14	70	66	—
15	12 (duplicates)	66	—
16	84	37 (rain)	—
17	55	66	—
18	24	50	—
19	18	22 (duplicates)	—
20	28	—	—
	Total 1059	**Total** 954	**Total** 802
	Range 16–84	**Range** 10–69	**Range** 12–104

A clear example of how slight, year to year, changes in the detection limit for an element in lake sediments can produce a major change in a regional map pattern came to light recently during the POTMAP (POTential MAPping) experiments (Fortescue, Vida, Rencz, and Wright, this volume).

The problem arose as follows. From 1987 to 1989, all OGS lake sediment geochemical data was obtained from one contractor. During this period, abundance data for a suite of 35 elements (plus loss on ignition) in each of over 3000 OGS lake sediment core samples was obtained. All the lake sediment samples were processed by 'the same methodology' during the three year period. In this study quality control (QC) data was obtained from OGS standard samples included at random in batches of unknowns. Results from the QC samples were then used to provide detailed information on the performance of the analytical methods used to determine each element (Fortescue and Vida 1989, 1990a, 1990b, 1991a, 1991b).

In the case under discussion, the QC data for antimony (Sb) revealed coefficients of variation (c/v) of 85.1% (at the 0.25 ppm level) and 69.0% (at the 0.67 ppm level) for lake sediments collected from the Trout Lake and Hanes lake map areas (Fortescue and Vida 1989, 1990a). Normally, element data sets with a c/v over 20% are considered unsuitable for image processing or use in a geographical information system (GIS).

This case was an exception, designed to demonstrate the effect of extremly noisy Sb data on the production of POTMAPS in the study area (*see* Plate I at back of volume). The Sb POTMAP (Plate VIIa, at back of volume) was very different from POTMAPS for other elements in the series because it showed three broad vertical bands extending northward across the map area. The Sb POTMAP also showed occasional "geochemical anomaly" peaks superimposed on the vertical bands. The regional geological map of the area (Plate I, at back of volume) shows that the strike of the geology in the area is at right angles to the bands on the Sb POTMAP. After the bands were checked to see that they were not due to an error in the data processing technique, another cause was investigated.

Eventually it was found that the POTMAP bands corresponded with areas from which lake sediments were collected in 1987, 1988, and 1989. Dr. Hart Bickler, the laboratory manager, then informed us that a slightly different Sb neutron activation technique was used for analysis of the samples in each of the three years in question. This explained the three bands on the Sb POTMAP. It is important to note that: 1) the bands were found only on the Sb POTMAP and not on the other maps based on more reliable element data (Plates III to VI, at back of volume); and 2) until the data processing experiment the existance of the bands was unknown to us owing to the noisy data set.

In summary, a small change in the limit of detection for Sb, (which was not significant from the viewpoint of Sb geochemical anomaly description), caused a major change in the POTMAP geochemical pattern plotted from the data. In this case the cause of the problem was found relatively simply.

In the context of the MLU, occasional slight variations of this type in multielement analytical techniques could seriously affect the overall validity of multielement geochemical map data. Such variations, occuring randomly, on a day to day, month to month, or year to year basis, could seriously interfere with the validity of regional geochemical maps. The two solutions to this problem in the MLU which have been proposed here are: 1) the complete standardization of MLU sample pre-processing and chemical analysis methods using exactly the same instrumentation and settings for entire geochemical projects; and 2) the inclusion of many types of QC samples within each batch of unknown samples on a daily basis.

SUMMARY

This paper has reviewed the objectives for the OGS mobile laboratory unit and indicated how this concept might be developed. The paper has also reviewed briefly plans for the initial operation of the MLU after it is constructed. In a later section of the paper, examples are given of the relationship between the rate of regional geochemical sampling and the planned rate of pre-processing and chemical analysis in the MLU during routine operation. The paper ends with a detailed example of the type of unexpected problem that may arise during processing of regional geochemical data if standardization and tight QC are not applied to the collection of multielement geochemical data.

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—— 1990b Geochemical survey, Herman Lake Area; Ontario Geological Survey, Map 80-804, scale 1:50 000

—— 1991a Geochemical survey, Pancake Lake area; Ontario Geological Survey, Map 80-807, scale 1:50 000.

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36. Project Unit 90–24. Analysis of Regional Geochemical Data using POTMAP, a Moving Average Technique

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INTRODUCTION

Since late 1989, the Ontario Geological Survey (OGS) has released five regional geochemical maps. Two more are currently being prepared (Fortescue, Vida and Wadge, this volume; Vida et al., this volume). Each map is, or will be, accompanied by a data base diskette which includes all associated positional and geochemical data for a map sheet.

These maps aim to present, describe and provide a brief interpretation of general geochemical patterns in the data likely to be important in mineral exploration. The data base diskettes provide digital data in a form suitable to input into personal computer (PC) software designed for analysis by: 1) detailed statistics, and/or 2) image processing, and/or 3) a geoscience geographical information system (GIS). A diagram of a hypothetical geoscience GIS of this type is illustrated in Figure 2.

The regional geochemical maps are designed to provide explorationists with geochemical data of similar scientific tenor to OGS digital geological and geophysical data at the 1:50 000 scale. For this reason, all stages of the preparation of the seven OGS regional geochemical maps were standardized as far as possible. Standardization included: 1) map planning, 2) sampling (of lake sediment and water samples), 3) sample pre-processing, 4) chemical analysis, 5) chemical data quality control procedures, 6) data processing methods, and 7) map marginal note descriptions. The standardized methodology is summarized in a flow diagram (Figure 3).

A PROBLEM WITH DATA DISPLAY ON REGIONAL GEOCHEMICAL MAPS

Two approaches are currently used to display element data patterns on the regional geochemical maps. These are: 1)"saw-tooth" diagrams (drawn as illustrated and described on Figure 4b), and 2)"dot-maps" as illustrated on Figure 4a.

So far the sawtooth diagrams have proven popular with

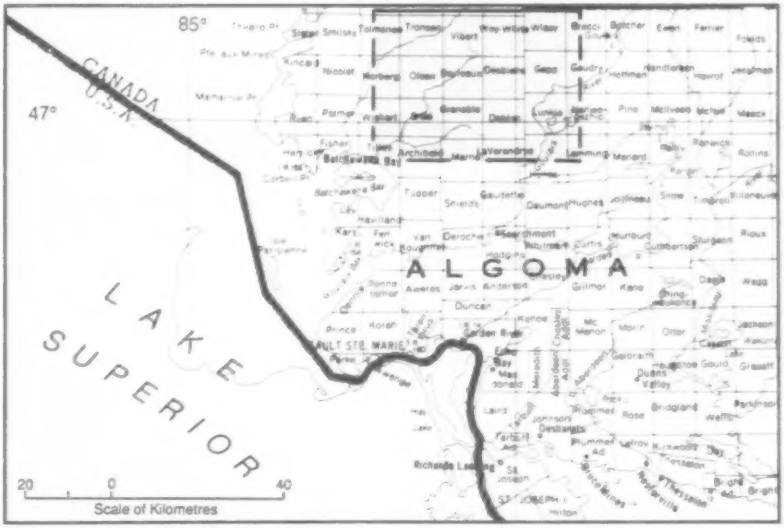

Figure 1. Location map of study area, scale 1:1 584 000.

explorationists because they include plots of all geochemical values (including anomalies) in a geochemical map data set.

The use of simple dot-maps to describe element geochemical province patterns has been less successful, as they are simplistic and do not indicate geochemical gradients associated with province patterns. Consequently, in order to increase the effectivness of the printed geochemical maps, a computational alternative to simple dot-maps has been required. Results of experiments along these lines are described in the remainder of this report.

POTMAPS

A.N. Rencz suggested that POTMAPS might be more effective than dot-maps to display element data on the OGS geochemical maps. This article describes an experimental application of the POTMAP approach to geochemical data obtained from a 2500 km^2 area of the Batchawana greenstone belt, situated 70 km northeast of Sault Ste Marie. The study area is included in parts of the OGS Trout Lake (Fortescue and Vida 1989) and Hanes Lake (Fortescue and Vida 1990) regional geochemical map sheets (*see* Figure 1).

THE USE OF POTMAPS FOR THE DISPLAY OF REGIONAL GEOCHEMICAL MAP DATA

The POTMAP technique is one of the thematic mapping techniques included in a software package provided by Tydac Technologies of Ottawa, Ontario. The word "POTMAP" is derived from the words " POTential" and "MAPping". This technique is particularly effective for processing geochemical data because it creates a smoothed surface map from random point data.

The POTMAP technique is based on two assumptions: 1) attribute values at any point on a map are related to attribute values of any of the points around it, and 2) this relationship weakens the further away the data points are from the point of interest. POTMAP calculates the effect of individual points on the data points surrounding them and, in doing so, produces a smoothed (averaged) surface with individual values never higher (or lower) than the maximums (or minimums) in the original data set. Advantages of using POTMAP for processing regional geochemical data are: 1) its flexibility, 2) its ability to average out noise and discount anomalous data points, and 3) a sphere of influence around each point can be established so that areas beyond this distance are not affected. These attributes are particularly important at the regional map scale.

THE COMPUTATION OF POTMAPS

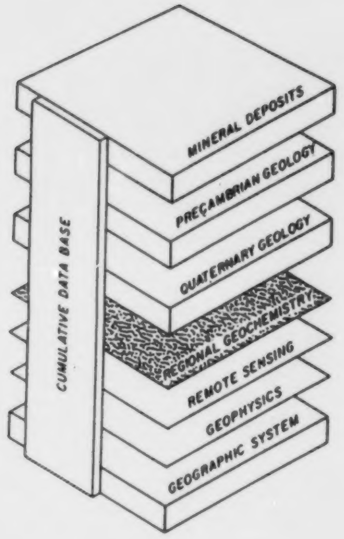

Figure 2. The role of regional geochemical maps in an idealized conceptual model of a hypothetical geoscience Geographical Information System (GIS) designed to collect information for mineral resource appraisal by a government agency. The database would cumulate from bottom to top of the diagram with preliminary image processing of data at each step (from Fortescue and Vida 1990).

POTMAPS are based on data obtained from concentric sampling circles which are considered to surround selected data points on a regional geochemical map. The POTMAP technique, as used in the experiment described here, applies a conical smoothing function (with a decay function of 0.5) to the data found within each of the concentric sampling circles surrounding selected data points. The average of all point values occurring in each set of sampling circles are calculated first. Values are then averaged to produce a new data value associated with the point at the centre of the sampling circles.

The radius of the largest sampling circle in a cluster is determined: 1) using Moran's statistic (which is calculated outside the Tydac system), 2) using Kriging routines, or 3) using an empirically determined radius. For the initial test of POTMAPS derived from the OGS data, an empirical radius, which had been proven suitable for regional geochemical map data processing, was used. Further information on the theory behind the POTMAP methodology can be obtained from the Tydac Technologies software manual (Anonymous 1989).

THE APPLICATION OF THE POTMAP APPROACH TO OGS REGIONAL GEOCHEMICAL MAP DATA FROM THE BATCHAWANA GREENSTONE BELT

A rectangular study area (35 km north–south and 70 km east–west), was chosen for a test of the POTMAP data processing technique. The first step was to digitize a generalized geological map of the study area (Plate I, at back of vol-

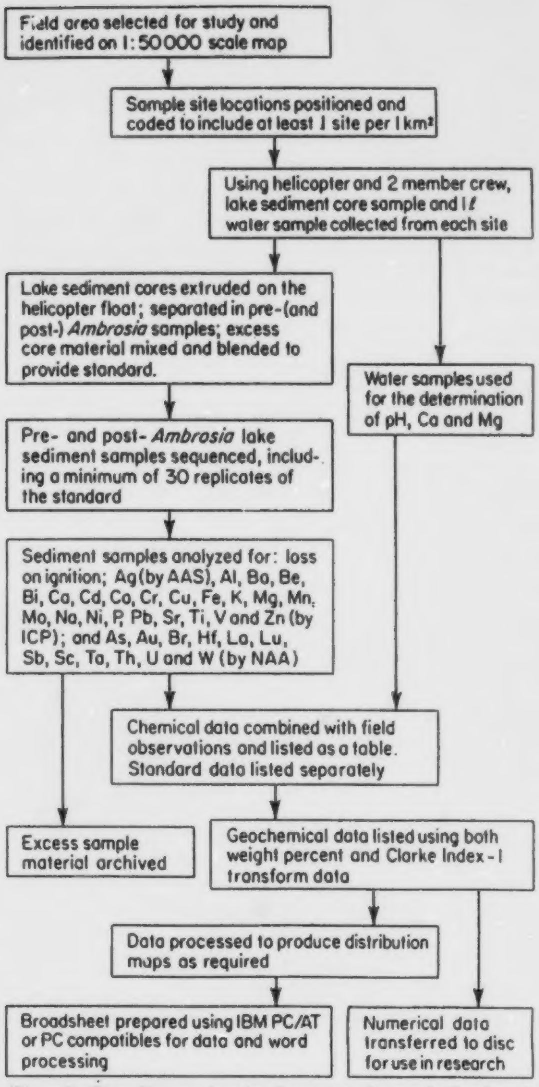
Field area selected for study and identified on 1:50000 scale map
Sample site locations positioned and coded to include at least 1 site per 1 km²
Using helicopter and 2 member crew, lake sediment core sample and 1 ℓ water sample collected from each site
Lake sediment cores extruded on the helicopter float; separated in pre-(and post-) *Ambrosia* samples; excess core material mixed and blended to provide standard.
Water samples used for the determination of pH, Ca and Mg
Pre- and post-*Ambrosia* lake sediment samples sequenced, including a minimum of 30 replicates of the standard
Sediment samples analyzed for: loss on ignition; Ag (by AAS), Al, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Sr, Ti, V and Zn (by ICP); and As, Au, Br, Hf, La, Lu, Sb, Sc, Ta, Th, U and W (by NAA)
Chemical data combined with field observations and listed as a table. Standard data listed separately
Excess sample material archived
Geochemical data listed using both weight percent and Clarke Index-1 transform data
Data processed to produce distribution maps as required
Broadsheet prepared using IBM PC/AT or PC compatibles for data and word processing
Numerical data transferred to disc for use in research

Figure 3. Flow diagram showing the steps in the standardized methodology for the preparation of OGS regional geochemical maps.

ume) obtained by digitizing parts of the published maps (Fortescue and Vida 1989 and 1990). Plate I shows that the entire area is underlain by Archean metavolcanic and metasedimentary rocks of the Batchawana greenstone belt and surrounded by granite of the Archean Precambrian shield. The supracrustal rocks strike east across the centre of the geological map (*see* Plate I at back of volume).

In most of the study area, the bedrock is covered by a thin layer of coarse textured glacial drift. These landscape conditions are particularly favourable for regional geochemical mapping based on lake sediments and waters. An exception to this type of drift cover occurs in the east–central part of Plate I where there is a relatively large patch of glacial moraine.

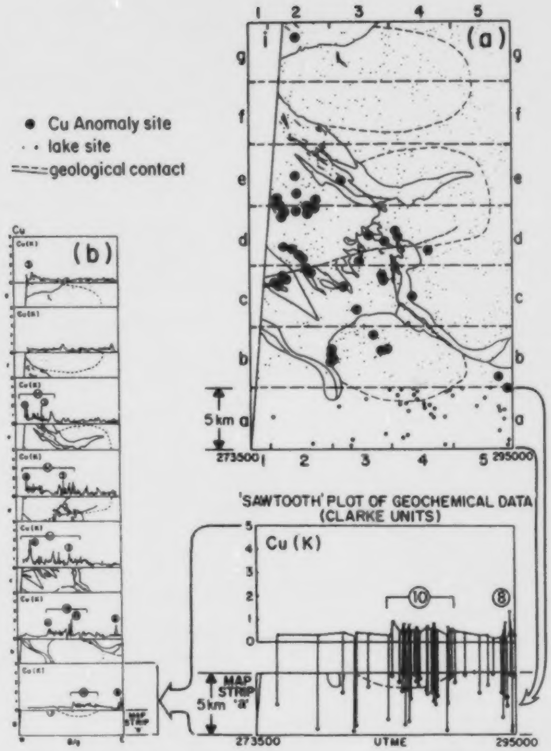
● Cu Anomaly site
· · lake site
====geological contact
(a)
(b)
1
2
3
4
5
g
f
e
d
c
b
a
i
5km
273500
295000
'SAWTOOTH' PLOT OF GEOCHEMICAL DATA (CLARKE UNITS)
Cu (K)
0
1
2
3
4
5
⑩
⑧
MAP STRIP
5km 'a'
UTME

Figure 4. An example of a 'dot map' (a) showing the steps in the preparation of a 'saw tooth' diagram (b) from the same data set (modified from Fortescue and Vida 1990).

During 1987, 1988 and 1989 a total of 1856 pre-*Ambrosia* lake sediment core samples (and associated lakewaters) were collected from the study area. The average sample density for the entire geochemical map is 1 sample per 1.35 km². Levels of 35 elements and Loss on Ignition (LOI) were determined in all the lake sediment core samples. The chemical analyses were carried out for the OGS under a 3 year agreement by Chemex Labs. Ltd. of Mississauga, Ontario. Calcium and magnesium were determined in the lakewater samples by the Geoscience Laboratories of the OGS and their pH was determined in a field laboratory within 24 hours of collection.

Six parameters were selected for the POTMAP experiment. These include; 1) lake sediment iron (Fe), 2) lake sediment uranium (U), 3) lake sediment arsenic (As), 4) lake sediment molybdenum (Mo), 5) lake sediment antimony (Sb), and 6) lakewater pH. The Sb POTMAP was found to include analytical errors and, for this reason, it is described separately by Fortescue (this volume).

QUALITY CONTROL OF GEOCHEMICAL MAP DATA

Quality control (QC) data for chemical analysis of pre–*Ambrosia* lake sediment core material included in the

Table 1. Precision data for elements in lake sediment 'standard' samples included in batches of Trout Lake and Hanes Lake unknowns (from Fortescue and Vida, 1989, 1990).
(C/V of 15% or less, normally acceptable for regional mapping)

	Trout Lake Map		Hanes Lake Map		
Element	mean	c/v	mean	c/v	Clarke Value (K)
Fe	.85%	8.3%	4.25%	4.8%	62,200 ppm
U	8.6 ppm	11.6%	.70 ppm	34.6%	2.3 ppm
A	1.8 ppm	45.3%	107.00 ppm	10.8%	1.8 ppm
Mo	1.5 ppm	41.3%	1.10 ppm	24.4%	1.2 ppm
(Sb	.25 ppm	85.1%	.67 ppm	69.0%)*	.2 ppm

**The Sb data are discussed by Fortescue (this volume)*

study are summarized in Table 1. These data were obtained from replicate analyses of OGS lake sediment samples included within batches of unknown samples. Forty–four QC replicates were included in the Trout Lake Map batch of samples (Fortescue and Vida 1989) and 69 replicates were included in the Hanes Lake batch (Fortescue and Vida 1990; *see also* Table 1).

On the OGS regional geochemical maps, if the coefficient of variation (c/v) of QC data for an element is less than 16% the corresponding unknown sample data is considered acceptable for detailed processing (e.g. by statistical analysis, image processing, or for inputting into a GIS). If the c/v of QC data for an element is greater than 15% but less than 30%, the corresponding unknown sample data is considered conditionally acceptable for detailed processing. If the c/v of QC data for an element is greater than 30% then data are considered unacceptable for detailed processing, even though "strongly anomalous" values for these elements (e.g. Au) can be of interest in mineral exploration.

If these criteria are applied to elements listed on Table 1, the Fe data set would be acceptable, and the data sets for U, As, Mo (and Sb) would be unacceptable. This selection was done deliberately to test the effectiveness of the POTMAP approach in smoothing different kinds of noisy data. It was assumed that if the POTMAP approach was successful with the noisy data it would be effective for the other element data sets as well.

THE PREPARATION OF THE POTMAPS

During a two day period in May 1991, D.F. Wright processed the geochemical data from the OGS study area at the geomathematical laboratory of the Geological Survey of Canada in Ottawa. The Tydac POTMAP software was used without modification. After some minor problems with the transfer of the OGS data were solved, a series of POTMAPS were produced. These were photographed and later reproduced here as Plates III, IV, V, VI, VII (found at the back of this volume). The white spots on some of the maps are artifacts and are not considered to affect the outcome of the experiments described here.

DESCRIPTION OF THE MAPS

The Geological Map (Plate I)

The geological map of the study area shows bedrock lithologies and some Quaternary lithologies as well. The map clearly delineates the areas of greenstone within the granitic rocks. The map also shows important Quaternary features including: 1) an area of ground moraine (dark grey) in the left centre of the map, and 2) areas of glaciofluvial cover (light grey) in the bottoms of major river valleys. On the POTMAPS, (Plates II - VII, back of this volume) the valley bottoms are black because they lack lake sample points and are therefore beyond the sphere of influence of any of the sampling circles.

The Lakewater pH Map (Plate II)

The ability of the POTMAP to describe a clearly defined geochemical province pattern is demonstrated by the lakewater pH map (Plate II). In this case the POTMAP shows a well defined geochemical province pattern associated with the area of glacial moraine cover just mentioned. The pH POTMAP also provides information on geochemical gradients associated with the province (Plate II). Incidentally, a POTMAP of Ca in water (not included here) has a pattern for "high Ca values" very similar to that on Plate II. A combination of evidence from 1) the pH POTMAP (Plate II), 2) the sawtooth pH plot (Plate II), and 3) the Ca POTMAP (not included here) indicates a cause and effect relationship between the moraine and the geochemical patterns.

POTMAP of Iron in Lake Sediments (Plate III)

Iron (Fe) was chosen as an example of a major element in lake sediment which is determined precisely in QC standards (*see* Table 1) and has a variable abundance in lake sediments due to local secondary accumulation. The Fe POTMAP (Plate III) clearly reflects the uneven distribution of Fe in lake sediments. In fact, the POTMAP pattern appears random across the entire map with scattered higher than normal values. This is in sharp contrast to the pH pattern just described. The Fe sawtooth diagram (Plate III) confirms the unevenness evident in the POTMAP pattern.

In summary, the Fe POTMAP shows a complex regional geochemical background pattern which requires more data processing to bring out its full significance to mineral exploration. Such a pattern would not normally be displayed on OGS regional geochemical maps.

POTMAP of Uranium in Lake Sediments (Plate IV)

The POTMAP uranium (U) pattern (Plate IV) shows two, sharply defined, geochemical province patterns associated with areas of granitic rocks on the geological map (Plate I). As in the case of the lakewater pH map (Plate II), geochemical gradients occur within the two U province patterns. The U sawtooth diagrams (Plate IV) provide details of the strong contrast in U values found in the study area. Incidentally, the U POTMAP failed to clearly resolve the two distinct levels of U values occuring in the large U province pattern in the southern part of the map area (*see* Fortescue and Vida 1989). In general, the U POTMAP patterns are considered important as examples of how this technique behaves when applied to noisy data sets with high contrast.

POTMAP of Arsenic in Lake Sediments (plate V)

The arsenic (As) POTMAP patterns (Plate V) are totally different from those for Fe and U described above. The As geochemical province is, however, similar to the pH pattern (Plate II) because it has an area of high values in the central part of the map. The As pattern differs from the pH pattern in having a west–southwest trending lobe of relatively high values extending towards the west boundary of the study area in the vicinity of greenstone belt rocks (Plate I). The complex, well defined, As POTMAP pattern suggests that it results from the interaction of several geochemical processes. The As data would be included in a regional geochemical map because some of them might be directly related to mineralization.

POTMAP of Molybdenum in Lake Sediments (Plate VI)

Molybdenum (Mo) is an element where the Clarke value (K=1.2 ppm) is close to the detection limit of the analytical method (1.0 ppm) quoted by the Contractor for the analysis of pre–*Ambrosia* lake sediment samples. As a result of this the c/v values recorded in the Mo QC test are consistantly unacceptably high (*see* Table 1). For this reason the Mo data is selected for a POTMAP test. The Mo POTMAP (Plate VI) is found to: 1) smooth out the noisy background data, and 2) focus attention on three small geochemical province patterns which show clearly in the sawtooth diagram (Plate VI). It was concluded that the Mo POTMAP provided explorationists with targets suitable for further investigation and for this reason would be included in a regional geochemical map.

CONCLUSIONS

A preliminary experiment involving the application of the POTMAP technique to 5 sets of regional geochemical map data demonstrated that POTMAPS are superior to dot–maps for the display of geochemical province patterns on regional geochemical maps of this type. It is recommended that POTMAPS replace dot–maps for the display of spatial regional element data on future OGS regional geochemical maps. In order to accentuate the geochemical patterns, the POTMAPS for the 8 percentile classes were reproduced here in colour. If used for routine geochemical mapping POTMAPS of this type may also be effectively displayed using selected grey tones.

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Geoscience Laboratories Programs

37. Summary of Activities 1991, Geoscience Laboratories Section

P.C. Lightfoot

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INTRODUCTION

This summary of activities reports some of the contributions achieved by the Geoscience Laboratories Section's staff members in 1990–91. The planning which has gone into the new geoanalytical facilities in the Mines and Minerals Research Centre (MMRC) is now showing physical manifestation on the campus of Laurentian University, Sudbury. There is still some way to go in terms of constructing and equipping the facility, decommissioning the present facility and commissioning the new facility, but what is very clear now is the potential of this geoanalytical laboratory to play a strategic role in the implementation of increasingly sophisticated geological, geochemical and environmental-geology programs. An increasingly geological and geochemical content to the activities of the Geoscience Laboratories Section is yielding important benefits; the new generation of geoanalysts come with geoanalytical, geological and geochemical credentials. This report focusses on some examples which demonstrate the importance of "bridging the gap" between geoanalytical and geological programs in order to maximize benefits to present and future client groups.

The following major laboratory activities are reported upon:

1. the continued implementation of a total quality-assurance program
2. the implementation of new technologies and the increased use of automation
3. communications and the development of joint programs and partnerships which foster stronger ties between the laboratories, client groups and the geoscience community
4. relocation-related activities
5. training, staff development, and laboratory safety

TOTAL QUALITY ASSURANCE

The geoanalyst, among other things, strives to achieve two main goals: 1) to produce validated data of sufficient accuracy and precision at appropriate abundance levels to solve geological problems; and 2) to promptly generate the data for a suite of representative samples, duplicates and standards.

Through the preparation of a field guide to sampling (Lightfoot and Riddle 1991) and the implementation of the Laboratory Information Management System (LIMS), much has been done to ensure that the quality of the data generated is not only controlled but also assured. This is done at many stages, commencing with the technician's approval and ending with the Section Chief's approval; different levels of quality control are applied throughout the sample-preparation and analysis scheme. As one example, the following quality-control (QC) checks are in place for routine determination of Au, Pt, Pd and Ag:

1. Crabtree and de Souza (this volume) have implemented a test to monitor contamination during sample preparation. Quartzite, used to clean the ring mill, is routinely ground as a

sample, and assayed for the precious metals. If any precious metals smear on the walls of the mill, then this test would pick up the effects.

2. Monitoring the variations in fire assay blanks ensures that the fluxes are reliable and that the sample preparation environment is clean (Crabtree and de Souza, this volume). The routine fire assay blank introduced by either flux or environmental contamination is monitored on a regular basis. The blanks are prepared following the conventional fire assay method (OGS 1990, *see* method MS–14).

3. Monitoring the analytical performance of the fire assay laboratory with reference to the MRB-series standards ensures validation of the data generated for samples (Crabtree and de Souza, this volume). The fire assay technician routinely prepares the Au-Ag MRB standard reference materials (MRB25–28) and the QC data is checked by the supervisor for any longer-term variations.

4. When the samples are logged in as a job, duplicates are identified by the sample-reception technician. The technician also identifies any MRB materials and international standards which should be analyzed along with the samples. The results for these standards are maintained on the Laboratory Information Management System (LIMS) data base for longer-term compilation of the analytical-capabilities guide.

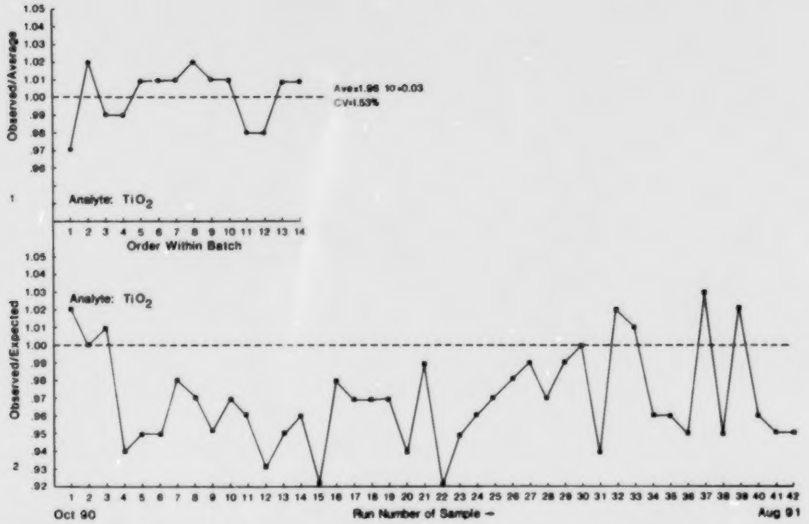
5. In a select number of jobs (roughly 1 in every 4), MRB in-house standards are introduced as unknowns (e.g., MRB25–28 for conventional fire assay). These materials cannot be distinguished from regular samples by any of the staff with the exception of the Chief Analyst. By monitoring these materials, the best-possible long- and short-term estimates of precision can be acquired. Traditionally, the GRB-series standards have been used (for which there is much data), but as supplies of these materials have dwindled, a new series of MRB materials have been prepared and introduced. The Chief Analyst now assesses both within-job and between-job precision using the MRB materials. The short-term performance is monitored with a control chart which documents within-batch performance on multiple preparations and analyses of the same in-house reference material.

These 5 steps in fire assay quality control illustrate to the client that the Geoscience Laboratories Section can produce data of high quality. This validation data is reported with batches of samples, archived into the LIMS and is available from the Chief Analyst.

Through the use of a blind-standards program, the blind-duplicates program, multiple analytical methods and the tracking of data for the in-house MRB series and international standards, a LIMS mechanism for the validation of data using control charts has been implemented. The quality-assurance manual, which is now being written by managerial, scientific and technical staff and edited by T. Hodges will document many of the protocols which are used by the laboratories to ensure the quality of the data produced (Project Unit 90–47).

The *Analytical Capabilities and Services* guide (Riddle 1989) documents the longer-term performance of the Geoscience Laboratories Section with respect to precision, accuracy and determination limits of different analytical methods and techniques. These statistics are regularly updated based on the blind-standards program which has been in place for 10 years and are valuable data in the context of multiyear programs where analytical work may be carried out over a period of several years. When viewed in this light, the results for some elements may not appear spectacular, but they are certainly realistic, reflecting the changes in methodology, technical and scientific staff over the past 10 years.

To illustrate within-batch versus longer-term precision, results for the determination of TiO_2 on powder pellets by X-ray fluorescence (XRF) have been compared (OGS 1990, method EA16). Figure 1 shows multiple within-batch analysis of the TiO_2 content of the Keweenawan basalt standard MRB–29; it also shows that there is little short-term drift and that the precision does not vary within the period of the analysis of one batch of samples. Of perhaps more importance is the longer-term performance with respect to reference materials, and Figure 2 shows TiO_2 data for the same material collected over the past year where MRB–29 was prepared and

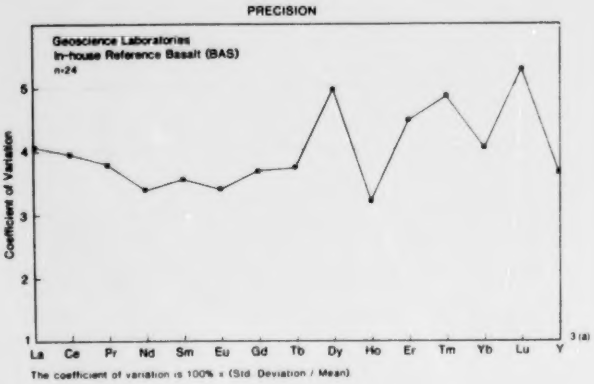


Figures 1 and 2. 1) Variation in the precision documented within a batch on the analysis of TiO_2 by XRF on different powder pellets using an MRB basalt standard (MRB–29). 2) Temporal variation in TiO_2 precision documented over time on the analysis of different powder pellets of an MRB basalt standard (MRB–29) analyzed as an unknown.

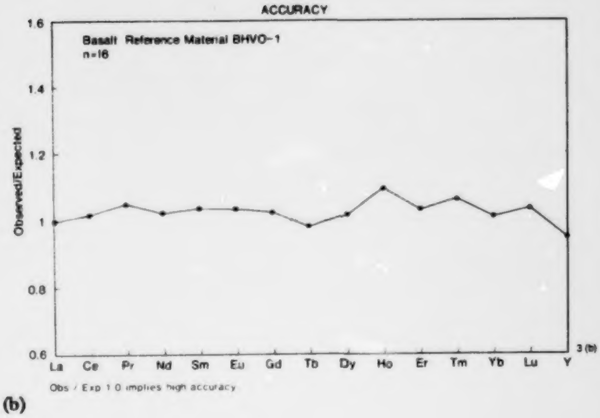
analyzed as an unknown. The precision for other analytes in MRB–29 is given in Table 1 based on within-batch analysis and between-batch data. Figures 3a and 3b show the precision and accuracy achieved by multiple analysis of an in-house basalt standard (MRB–29) and the international basaltic reference standard (BHVO–1), together with determination limits (Figure 3c) achieved by the method (inductively coupled plasma mass spectrometry (ICP–MS)). The results (reported by Lightfoot and Doherty at Geoanalysis 90) suggest that within-batch precisions and accuracies for many of the petrogenetically important analytes of 5% (2σ), or better, can be achieved on a highly routine basis. Longer-term, routine accuracies and precisions of 5% (2σ), or better, can be achieved for all analytical work by ensuring that the standard reference material values reported are within this tolerance. This illustrates that quality can not only be controlled (i.e., above or below that identified in the *Analytical Capabilities and Services* guide), but it can also be assured to be better than the critical limits established in the guide. The precision, accuracy and determination limits presented in the *Analytical Capabilities and Services* guide forms a useful basis for the regular update of the priorities of the laboratories' internal Science Board in terms of improving or introducing new capabilities (*see* Table 2).

Quality-control programs have been implemented in many areas of the Geoscience Laboratories; the importance of double-method validation in the control of digestion problems was illustrated by Richardson et al. (1990) with reference to insoluble minerals such as zircons. Zircon is primarily a zirconium silicate ($ZrSiO_4$); this mineral is also a sink for the heavy rare earth elements (e.g., Yb), and the high field-strength elements (such as Y and Hf). The formulation of a petrogenetic hypothesis and the classification of rock types have traditionally rested heavily on the results for data on petrogenetically important trace elements where determinations can be influenced by insoluble minerals such as zircon. For many mafic and ultramafic rocks, zircon is unlikely to be an important mineral phase; in granitic systems, the issue of zircon control is very important. By monitoring the effectiveness of digestion protocols, appropriate quality-assurance controls are in place to alert the geologist of the possibility of a zircon digestion problem. If the data for these elements are critical to the geological investigation, then a time-consuming alkali-fusion procedure can be performed to quantitatively determine these analytes.

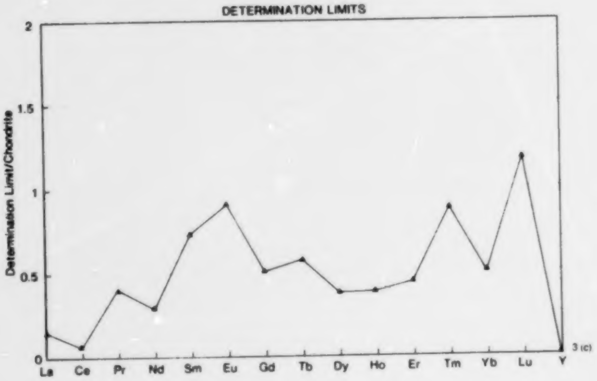
Determinations of analytes by digestion and spectroscopic methods relies heavily on the fundamental assumption that solutions of the analytes of interest are stable with respect to external conditions and time. An HF-stabilization method was developed which ensured that critical, petrogenetically important analytes, such as Ta, Nb, Zr and Hf, were stabilized in the aliquot of



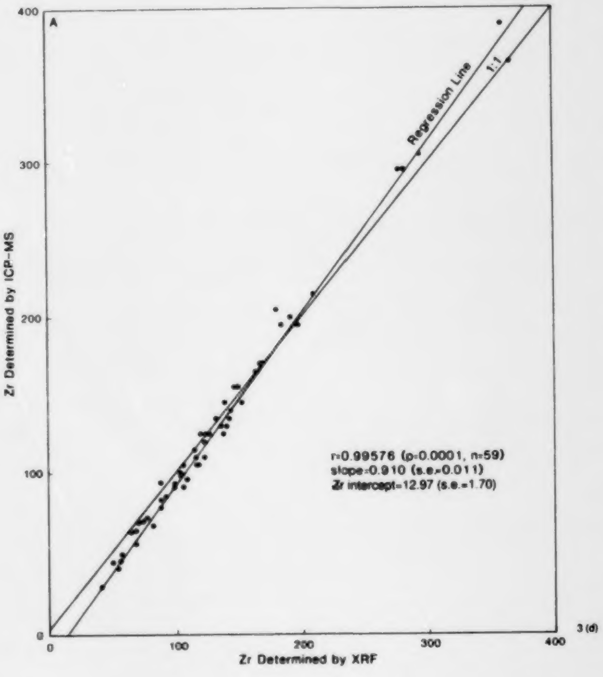
(a)



(b)

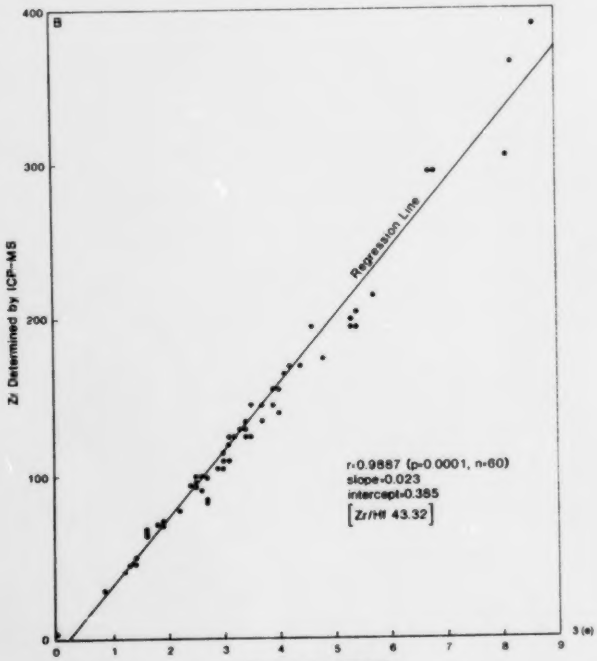


(c)



(d)

Figure 3. Variation in a) precision, b) accuracy and c) determination limits for petrogenetically important trace elements determined by ICP–MS. The results for precision and accuracy are based on separate digestions of an MRB basalt and international standard BHVO–1 by 3 different technical staff over a period of several months. d) Variation in Zr concentrations determined by ICP–MS versus XRF. e) Variation in Zr and Hf concentrations determined by ICP–MS. These data include mafic to felsic volcanics from the Keweenawan Supergroup (Lightfoot, unpublished data).



(e)

MRB-29	(Within-batch)		(Between-batch)	
	Average	1σ	Average	1σ
SiO_2 (X)	49.11	0.16	49.84	0.34
TiO_2 (X)	1.96	0.03	1.91	0.07
Al_2O_3 (X)	12.65	0.05	12.71	0.25
Fe_2O_3 (X)	13.61	0.09	13.52	0.07
MnO (X)	0.19	0	0.19	0.02
MgO (X)	6.13	0.09	6.09	0.17
CaO (X)	6.53	0.04	9.28	0.09
Na_2O (X)	2.45	0.07	2.53	0.18
K_2O (X)	0.69	0.01	0.72	0.02
P_2O_5 (X)	0.25	0.01	0.24	0.01
LOI (X)	2.95	0.06	n.a.	n.a.
CO_2 (X)	0.67	0.01	n.a.	n.a.
S (I)	0.02	0	n.a.	n.a.

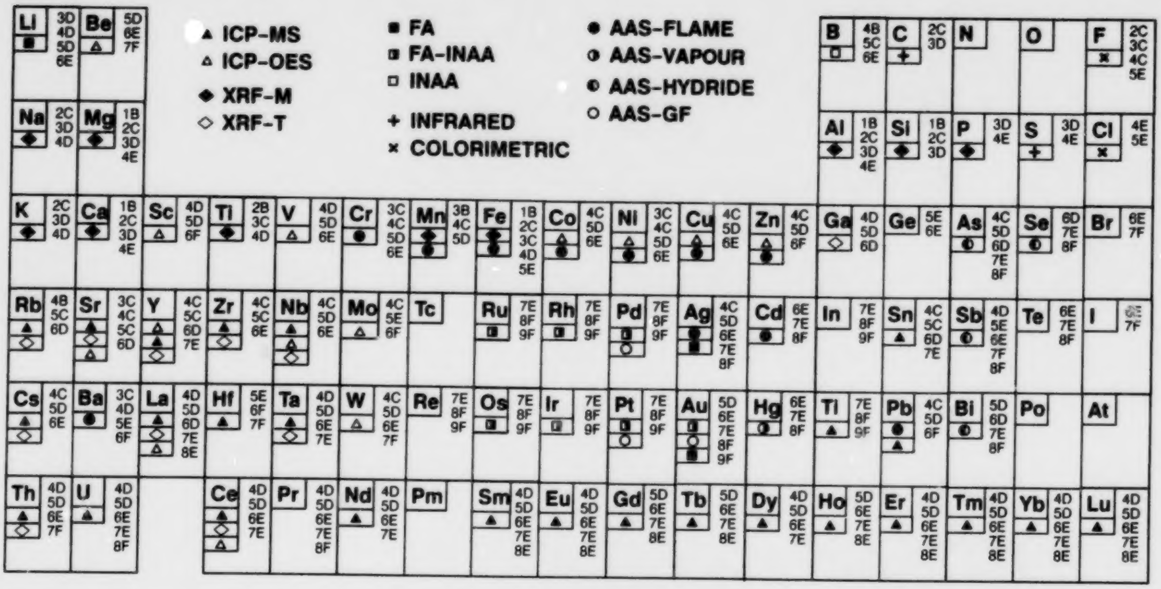
MRB 29	(Within-batch)		(Between-batch)	
ppm	Average	1σ	Average	1σ
Co (A)	47	1	43 45 (O)	2 3 (O)
Cr (A)	254	6	248	19
Cu (A)	150	16	145 (O)	17 (O)
Ni (A)	91	13	102 98 (O)	3 9 (O)
Zn (A)	117	5	109 116 (O)	5 4 (O)
Y (O)	n.a.	n.a.	24.3 (A)	0.8 (A)
Sc (O)	29	1	30.1	1.1
V (O)	282	8	289	1
Nb (M)	14.1	0.3	12 (X)	2 (X)
Rb (M)	14.7	0.5	18.5 (X)	1.4 (X)
Sr (M)	311	13	320 (X)	3 (X)
Zr (M)	173	13	180 (X)	2 (X)
Ta (M)	0.84	0.03	n.a.	n.a.
Hf (M)	4.64	0.14	n.a.	n.a.
Cs (M)	0.23	0.01	n.a.	n.a.
La (M)	20.38	0.49	21.18	0.61
Ce (M)	48.85	0.77	49.8	1.2
Nd (M)	27.69	0.46	28.11	0.66
Pr (M)	6.30	0.11	n.a.	n.a.
Sm (M)	6.21	0.13	6.32	0.18
Pr (M)	6.30	0.11	6.33	0.19
Sm (M)	6.21	0.13	n.a.	n.a.
Eu (M)	1.94	0.05	1.93	0.09
Gd (M)	5.46	0.13	5.60	0.19
Tb (M)	0.83	0.02	0.82	0.05
Dy (M)	5.10	0.10	5.12	0.22
Ho (M)	1.00	0.03	1.01	0.03
Er (M)	2.55	0.06	2.64	0.06
Tm (M)	0.37	0.01	0.37	0.01
Yb (M)	2.35	0.06	2.42	0.07
Lu (M)	0.35	0.01	0.35	0.01
Yn (M)	25.08	0.27	25.7 26.7 (X)	0.9 1.0 (X)

Footnotes:

X - X-ray fluorescence
M - Inductively-coupled plasma mass spectrometry
O - Inductively-coupled plasma optical emission spectrometry
A - Flame-atomic absorption
I - Infrared

n.a. - not available

Table 1. Precision archived on MRB–29 based on within-batch analysis and analysis over a one year period.


▲ ICP-MS
△ ICP-OES
◆ XRF-M
◇ XRF-T
■ FA
◨ FA-INAA
□ INAA
+ INFRARED
× COLORIMETRIC
● AAS-FLAME
◑ AAS-VAPOUR
◐ AAS-HYDRIDE
○ AAS-GF
Li 3D 4D 5D 6E
Be 5D 6E 7F
B 4B 5C 6E
C 2C 3D
N
O
F 2C 3C 4C 5E
Na 2C 3D 4D
Mg 1B 2C 3D 4E
Al 1B 2C 3D 4E
Si 1B 2C 3D
P 3D 4E
S 3D 4E
Cl 4E 5E
K 2C 3D 4D
Ca 1B 2C 3D 4E
Sc 4D 5D 6F
Ti 2B 3C 4D
V 4D 5D 6E
Cr 3C 4C 5D 6E
Mn 3B 4C 5D
Fe 1B 2C 3C 4D 5E
Co 4C 5D 6E
Ni 3C 4C 5D 6E
Cu 4C 5D 6E
Zn 4C 5D 6F
Ga 4D 5D 6D
Ge 5E 6E
As 4C 5D 6D 7E 8F
Se 6D 7E 8F
Br 6E 7F
Rb 4B 5C 6D
Sr 3C 4C 5C 6D
Y 4C 5C 6D 7E
Zr 4C 5C 6E
Nb 4C 5D 6E
Mo 4C 5E 6F
Tc
Ru 7E 8F 9F
Rh 7E 8F 9F
Pd 7E 8F 9F
Ag 4C 5D 6E 7E 8F
Cd 6E 7E 8F
In 7E 8F 9F
Sn 4C 5C 6D 7E
Sb 4D 5E 6E 7F 8F
Te 6E 7E 8F
I 6E 7F
Cs 4C 5D 6E
Ba 3C 4D 5E 6F
La 4D 5D 6D 7E 8E
Hf 5E 6F 7F
Ta 4D 5D 6E 7E
W 4C 5D 6E 7F
Re 7E 8F 9F
Os 7E 8F 9F
Ir 7E 8F 9F
Pt 7E 8F 9F
Au 5D 6E 7E 8F 9F
Hg 6E 7E 8F
Tl 7E 8F 9F
Pb 4C 5D 6F
Bi 5D 6D 7E 8F
Po
At
Th 4D 5D 6E 7F
U 4D 5D 6E 7E 8F
Ce 4D 5D 6E 7E
Pr 4D 5D 6E 7E 8F
Nd 4D 5D 6E 7E
Pm
Sm 4D 5D 6E 7E 8E
Eu 4D 5D 6E 7E 8E
Gd 5D 6E 7E 8E
Tb 5D 6E 7E 8E
Dy 4D 5D 6E 7E
Ho 5D 6E 7E 8E
Er 4D 5D 6E 7E 8E
Tm 4D 5D 6E 7E 8E
Yb 4D 5D 6E 7E 8E
Lu 4D 5D 6E 7E 8E

2a

Table 2. Classification scheme for range and precision of analytical determinations used to establish the revised Analytical Capabilities Action Plan (devised and implemented by Dr. Chris Riddle). To illustrate the use of this table, the coding 3C, 4C, 5C, and 6D shown by Sr in the periodic table (Table 2a) indicate that the geologist requires Sr data in the range 1% to 1 ppm (Table 2b) with precision (2σ) of ±2% at the high level and ±0.05% at the lower concentration extreme (Table 2b).

2b

	RANGE	PRECISION (2σ)	A ±0.5%	B ±1%	C ±2%	D ±5%	E ±10%	F ±20%	G ±50%	H ±100%
MAJOR	1	100 wt % 50 10	±0.5 ±0.25 ±0.05	±1.0 ±0.5 ±0.1	±2.0 ±1.0 ±0.2	±5.0 ±2.5 ±0.5				
	2	10 5 1	±0.05 ±0.025 ±0.005	±0.1 ±0.05 ±0.01	±0.2 ±0.1 ±0.02	±0.5 ±0.25 ±0.05	±1.0 ±0.5 ±0.1			
MINOR	3	1.0 0.5 0.1	±0.005 ±0.0025 ±0.0005	±0.01 ±0.005 ±0.001	±0.02 ±0.01 ±0.002	±0.05 ±0.025 ±0.005	±0.1 ±0.05 ±0.01	±0.2 ±0.1 ±0.02		
	4	1000 PPM 500 100	±5.0 ±2.5 ±0.5	±10 ±5 ±1	±20 ±10 ±2	±50 ±25 ±5	±100 ±50 ±10	±200 ±100 ±20	±500 ±250 ±50	
TRACE	5	100 50 10		±1.0 ±0.5 ±0.1	±2.0 ±1.0 ±0.2	±5 ±2.5 ±0.5	±10 ±5 ±1	±20 ±10 ±2	±50 ±25 ±5	±100 ±50 ±10
	6	10 5 1			±0.2 ±0.1 ±0.02	±0.5 ±0.25 ±0.05	±1.0 ±0.5 ±0.1	±2.0 ±1.0 ±0.2	±5 ±2.5 ±0.5	±10 ±5 ±1
ULTRA-TRACE	7	1000 PPB 500 100				±50 ±25 ±5	±100 ±50 ±10	±200 ±100 ±20	±500 ±250 ±50	±1000 ±500 ±100
	8	100 50 10					±10 ±5 ±1	±20 ±10 ±2	±50 ±25 ±5	±100 ±50 ±10
	9	10 5 1						±2.0 ±1.0 ±0.2	±5 ±2.5 ±0.5	±10 ±5 ±1

sample retained for analysis (Doherty, this volume). The considerable improvement in accuracy now means that these analytes can be determined with precisions and accuracies of 5% (2σ) or better.

Figure 3d illustrates the fact that comparable Zr values can be generated by the ICP-MS and XRF methods on mafic to intermediate rocks. The data fall on a reasonably tight array with an intercept of close to 10 ppm Zr on the XRF-method axis, and a slope of approximately 1. This suggests that basalt Zr data can be routinely acquired from the same solution that is used for the determination of the rare earth elements (REE).

Figure 3e compares Zr and Hf data determined by ICP-MS. These data define a tight array with Zr/Hf ≈ 43. For basaltic rocks, this ratio is relatively constant (like Nb/Ta) and can be used as a diagnostic criterion if Hf data (determined by ICP-MS) are available, yet Zr data are determined by XRF. A significant shift in the ratio above Zr/Hf ≈ 43 may reflect control by insoluble mineral phases; a deviation below Zr/Hf ≈ 43 may reflect instability of the solution.

NEW TECHNOLOGIES AND AUTOMATION

Over the last year, the Geoscience Laboratories Section has lost over 50% of its permanent staff to either secondment or training and development opportunities with other Ontario government ministries. This series of events has generated some quite unusual challenges in terms of maintaining routine productivity while implementing new methodologies. Much can be done to ensure that new staff and contract employees are trained to perform duties safely, correctly and routinely. One of the key reasons why the Geoscience Laboratories Section has been able to keep up a reasonable level of both productivity and sample-turnaround time has come from the introduction of several pieces of new, automated technology over the past year. Some of the significant breakthroughs in terms of productivity have come from the acquisition of 3 new pieces of technology in the sample-preparation laboratory; namely, a laboratory jaw crusher, a soil crusher, and a homogenization mixer. The soil-grinder system, implemented by H. de Souza and R. Samaroo, has had the most significant impact, as it reduces sample-preparation time for grain-size analysis, carbonate analysis, clay-mineral analysis, Atterberg limits and other physical-testing methods. The system also removes some of the subjectivity traditionally associated with the breaking of particles during preparation of coagulated clays and silts. The impact of this system to our present client group will be largely felt by engineering and terrain geologists, environmental geologists and geochemists, all of whom will benefit from more rapid sample turnaround on grain-size-analysis and assay-work requests on unconsolidated tills and sediments.

Automated technologies have also been introduced in the thin-section laboratory by D. Crabtree, where a lap and a vacuum press are used in the development of sample-preparation protocols for the production of highly polished thin sections for micromineralogical studies. In the mineral-processing laboratory, a Magstream separator is now used in conjunction with the Frantz isodynamic magnetic separator in the preparation of mineral concentrates (OGS 1990, method MS7-1). The importance of acquiring clean mineral samples for petrogenetic and economic studies has been highlighted elsewhere (e.g., Sutcliffe et al. 1990; Lightfoot et al., this volume) and will be critical in establishing an isotope-ratio program in the MMRC in Sudbury.

The Magstream™ unit is under evaluation as a possible tool in the field and may also be a valuable resource in the context of the Mobile Laboratory Unit (MLU) programs.

Development work continues in the X-ray diffraction (XRD) laboratory. The automated sample-changer system permits up to 40 samples to be analyzed overnight (*see Mines and Minerals Monthly Update*, November, 1990), and an autointerrupt facility permits the XRD scientist to interrupt a run to analyze a priority sample for a client. H. de Souza and S. Petrov have made considerable progress in the implementation of an automated modal-analysis capability (*see* de Souza et al. 1991; Petrov 1991). This system and the image-analysis system have the capability to automate many of the routine modal-analysis tasks routinely undertaken by the geologist with a point counter. The experience developed on the image analysis unit will be directly transferable to the electron microprobe in the MMRC, Sudbury, where the added dimension of digital elemental mapping will provide the geologist with a formidable array of tools in petrochemical studies.

Technological changes have had a significant impact in the Spectroscopy Subsection's laboratory. An autotitration system has been configured for use in the determination of FeO by J. Richardson and is now used to facilitate the rapid determination of this analyte. The implementation of this system has replaced a tedious and less-accurate manual method. In the XRF laboratory, the automatic-fluxer system is now used to simultaneously prepare up to 6 glass discs for the determination of major-element oxides. This system was brought on line by J. Richardson and S. Vijan. The importance of this equipment in terms of productivity was emphasized at the Prospectors and Developers Association meeting in 1991, where J. Richardson and S. Vijan presented a poster display. Interest in the system was shown by many delegates, and at least 1 assay company has now acquired automated technology for this routine sample-preparation task. In the inductively coupled plasma (ICP) laboratory, progress in the implementation of new analytical capabilities on the ICP-MS under the Geoscientist IV program continues (Doherty, this volume). A project has been implemented to document the results of work on the high-resolution inductively coupled plasma optical emission spectroscopy (ICP-OES) system. In co-operation with Leco Ltd., a publication will be issued by the Ontario Geological Survey which documents the spectral characteristics of this high-resolution ICP-OES system (Project Unit 90-46).

The most-unifying initiative which has automated many tasks within the Geoscience Laboratories Section was implemented by C. Riddle in 1989—the Laboratory Information Management System (LIMS). This initiative has been very valuable as it permits samples and data to be tracked efficiently during a period of rapid staff turnover. The LIMS is now fully functioning, and although program "bugs" continue to crop up, the automated transfer of data from both the two ICP units and the XRF is now routine. Manual data-entry protocols, QC tracking, and report-generation programs have all been modified, and now both assay and job certificates are routinely generated directly by the LIMS. Much effort by D. Rowell, P. Wong and G. Chai has made this possible. Front-end support with training and programming has benefited from efforts by G. Henri to ensure correct configuration of the instruments hosted within the LIMS.

COMMUNICATIONS, JOINT PROGRAMS AND PARTNERSHIPS

The Geoscience Laboratories Section's client group has traditionally consisted largely of geologists employed by the Ministry of Northern Development and Mines. External clients have included prospectors and those who have a requirement for research-type analytical work. Figure 4a shows a pie chart which identifies the relative number of clients in each of the groups based on the present LIMS client list. The relative breakdown on analyses requested by each of these client groups is shown in Figure 4b, where the relative proportions of work completed are expressed in terms of equivalent determinations (an equivalent determination is defined as the resource cost of 1 gold determination). The largest number of equivalent determinations were completed for the Precambrian Geology Section and reflect the considerable amount of effort which goes into the determination of up to 60 analytes for each sample which is submitted.

Activities and capabilities have been communicated at external forums. The Geoscience Laboratories Section's staff presented talks, posters and papers at the 1990 Mines and Minerals Division Open House meeting, the 1991 Prospectors and Developers Association meeting, the 1991 GAC-MAC-SEG meeting in Toronto, the 1991 Spectroscopy Society of Canada meeting, and the 1991 Canadian Mineral Analysts meeting. The list of papers at the end of this review reflects the valuable contributions made by many staff. Visits to the Canada Centre for Mineral and Energy Technology (CANMET), in Ottawa, to discuss a joint geostandards program, and to Laurentian University to raise awareness of the Geoscience Laboratories Section's activities were undertaken by the Acting Chief. J. Richardson toured a number of resident geologists' offices to raise awareness of the analytical capabilities of the Geoscience Laboratories Section and to promote laboratory safety.

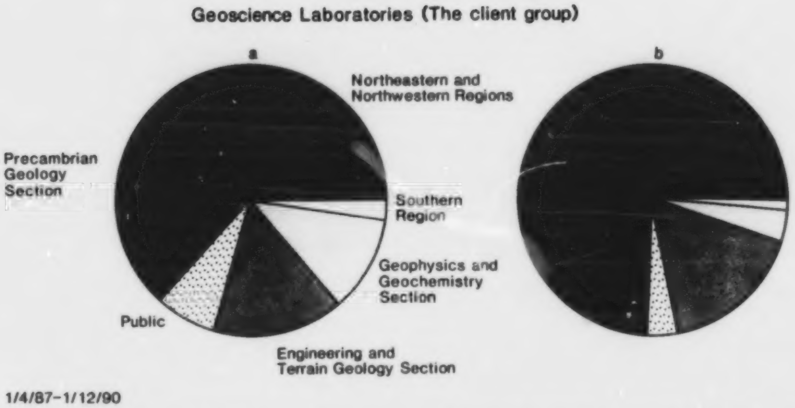


Figure 4. The client group and routine productivity. a) Pie diagram showing the composition of the client group. b) Pie diagram showing the proportions of work (by equivalent determination) performed for each client of the client group.

Contributions were made to the Mines and Minerals Division Monthly Reports and to the newsletter, *Compass*, to provide news updates on technological developments, technology transfer, the MMRC laboratory facility, and automation (*see* Selected References list). The release of OGS publications included a software program devised by Mustard and Richardson (1990) for the plotting of data into ternary figures. This software release has resulted in over 100 requests for copies of the software program from universities, industry and government.

Interaction with industry, universities and colleges was fostered through a number of initiatives in 1990. Five students from Ryerson Polytechnical Institute, Toronto, were provided with an opportunity to assist the Geoscience Laboratories Section with methods development through the completion of their BA theses. Staff from the University of Toronto's departments of Geology and Chemistry assisted with the development of quantitative-mineralogy studies, and their own programs of activities benefited from both qualitative and quantitative X-ray diffraction data. In a program to characterize the MRB29-32 and the fire assay flux for platinum group elements (PGE), G. Wilson of the ISOTRACE facility, University of Toronto, and R. Keays of Melbourne University, Australia, are involved in the characterization of the PGE levels in these materials.

In the context of establishing a centre for the geosciences in Sudbury, the Mineral Development and Lands Branch of the Mines and Minerals Division has been provided with a firm mandate to develop stronger ties with other organizations. Partnerships with CANMET to develop a joint geostandards program have been the subject of discussion: potential exists to use the MMRC geostandards facility to generate standard-reference rock powders, mineral powders and mineral mounts for the geoanalytical and assay community.

In a first, formal step to promote the visiting-scientist exchange program to be implemented in the MMRC facility, the OGS, the University of Toronto, and the Institute of the Geology of Ore Deposits, Petrology, Mineralogy, and Geochemistry (IGEM) of the Soviet Academy of Sciences have agreed to perform joint studies on the Abitibi (Ontario) and Pechenga (USSR) greenstone belts in order to better understand the geological environment in which magmatic sulphides carrying Ni, Cu and the PGE form. The OGS has also contributed to a joint program between the University of Toronto, the Institute of Experimental Mineralogy, the USSR Academy of Sciences, and the Soviet Central Geological Institute (TsNIGRI) on the geology of the Noril'sk nickel sulphide deposits (Lightfoot et al. 1990, 1991; Naldrett et al. 1991 and in prep.). An exploration model based on the Mg-number and Ni content of mafic intrusive rocks and on the indices of the degree of crustal contamination (such as Sr- and Nd-isotopes, light and/or middle REE ratios, and SiO_2 abundance) may be of value in the identification of magmas which have segregated sulphides enriched in Ni, Cu and the PGE (e.g., Naldrett et al. 1991).

As part of the program of activities, P. Lightfoot and A.J. Naldrett visited the Noril'sk nickel camp, USSR, in June of 1991. A report on this visit is published in the ***Mines and Minerals Monthly Update*** (September, 1990); the study reflects a strong willingness to continue co-operative research by exchanging scientific information and standard reference materials. The visit included surface field work and an underground visit to the Taimyr Mine at Noril'sk where massive sheets of nickel sulfide ore were viewed and sampled. The Geoscience Laboratories Section and the Noril'sk Kombinant laboratories agreed to exchange PGE reference materials. Much was gained from this visit, and an agreement was reached to invite Soviet scientific staff to present papers at an international symposium on the geology of the Noril'sk and Sudbury deposits to be held in Sudbury in the autumn of 1992.

In December of 1990, the Geoscience Laboratories Section was visited by N. Gorbachev of the Institute of Experimental Mineralogy, Soviet Academy of Sciences. N. Gorbachev and W. Doherty worked closely on the determination of the petrogenetically important elements, such as the rare earths, in samples from experimental charges designed to investigate the partitioning of elements between magmas and fluids during ore-forming processes.

Promoting the appropriate application of geoanalytical data in geoscientific studies has been the focus of a new Geoscience Laboratories Project (Project Unit 90–48), which is intended to bridge the gap between the geoanalyst, geologist and geochemist. In a first step towards this goal, the Geoscience Laboratories Section released *An Introductory Guide to Sampling for Geoanalysis* (Lightfoot and Riddle 1991) which can be used to ensure that appropriate sampling protocols are in place by the client groups. Contributions to *A Handbook on the Analysis of Geological Materials* have been solicited from 3 members of the Ontario Geological Survey by the editor, C. Riddle. Contributions on the geoanalytical requirements of the geologist (Sutcliffe, in prep.), sampling programs (Richardson, in prep.) and the interpretation of geoanalytical data (Lightfoot, in prep.) have been submitted. This will be the first step in the development of a plan for an OGS publication on the interpretation of geoanalytical data.

The demonstration of the applicability of new methods of geoanalysis is frequently the best way to gain interest from the client. In a recent study of the geochemistry of the Nipissing diabase (Lightfoot et al., this volume), the combined approach of having studied whole-rock geochemistry, mineral chemistry and the geochemistry of sulphides provided a firm basis for understanding the origin and evolution of Nipissing diabase magmas and a basis by which the whole-rock geochemistry might be used to evaluate the mineral potential of intrusions (*see* Lightfoot et al., this volume).

RELOCATION ACTIVITIES

Relocation-related activities have been identified as one of the highest priorities of Geoscience Laboratories Section staff. Further contributions to the design of the facility at the MMRC were provided in 1990; the collation of information on equipment, and planning of the decommissioning of the Toronto facility and commissioning of the Sudbury facility have commenced. Relocation will necessitate the transfer of major scientific instruments to Sudbury, a large number of smaller systems, much laboratory hardware, chemicals and some consumables. The relocation of chemicals requires an up-to-date inventory and approvals to transport hazardous materials; this is being completed with assistance from the Health and Safety Office of the Ministry of Northern Development and Mines. The Geoscience Laboratories Section is also establishing an emergency-response team which will deal with situations such as spills of hazardous chemicals. In this context, the safety training program for the staff will provide a firm basis for the maintenance of a safe working environment.

Over the past few years, micromineralogical work has been performed using facilities at the University of Western Ontario and the University of Toronto. A new micromineralogical facility will be available for use in the MMRC laboratories in Sudbury. The establishment of this facility and planning for its operation has been an ongoing task. Likewise, the establishment of the clean radiogenic-isotope laboratory facility has required specific attention to the design and construction of specialized equipment resistant to corrosion by acids and free of trace contaminants.

GEOSCIENTIST IV PROGRAM

The Geoscientist IV program in the Geoscience Laboratories Section continued in 1991 with W. Doherty in charge of developing methodologies for the determination of petrogenetically important trace elements and the platinum group of elements.

In August, 1991, W. Doherty was awarded the Barringer Prize by the Spectroscopy Society of Canada for his outstanding work on the internal-calibration scheme, the development of a new skimmer design for the ICP-MS, and for his applied efforts towards ensuring that the client group acquires data of sufficient quality to solve the geological problems at issue. At the 1991 Spectroscopy Society of Canada conference in Ottawa, W. Doherty presented a keynote-address paper on the ICP-MS method and highlighted the importance of this method in the geosciences.

TRAINING

The Geoscience Laboratories Section continues to implement a vigorous and effective training and development plan which ensures that employees are trained in many aspects of computer technology, safety, operation of equipment and are able to attend conferences where they can present papers and/or posters. The impact of adequate training during the rapid staff-turnover period prior to relocation has provided significant rewards: these include continued productivity and advancement of some staff members. Some of the highlights of the training and development plan included a visit by D. Crabtree to a conference and meeting dedicated to methods for the preparation of thin sections, polished sections and slabs. Information gained at this meeting will be critical in establishing the micromineralogical program in the MMRC laboratories. Staff members attending a specific course on the LIMS have benefited by an increased awareness of the operation of the system.The staff have been better able to routinely troubleshoot problems on the system and ensure that certificates for both jobs and assays are routinely produced.

Safety training continues to be a top priority. A hazardous spills control course has been organized, and WHMIS (Workplace Hazardous Materials Information System) training continues on site. The Geoscience Laboratories Safety Group continues to assist in resolving safety problems under the chairmanship of P. Okanski, and in 1991 the new Safety Manual was released by the staff of the Geoscience Laboratories Section with key editorial input provided from P. Okanski and J. Richardson.

ACKNOWLEDGMENTS

The staff of the Geoscience Laboratories Section are thanked for their efforts during this challenging time prior to relocation, as is C. Riddle for his wisdom and V.G. Milne for supporting the laboratories and realizing their potential. J. Boyd drafted the diagrams and H. Hahn typed the manuscript.

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38. Project Unit 91-16. Geological Applications of Laser Ablation ICP–MS

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INTRODUCTION

Inductively coupled plasma mass spectrometry (ICP–MS) is now established as a powerful tool for simultaneous multi-element and isotopic rock analyses (Riddle et al. 1988). The conventional method of sample introduction for ICP–MS has been nebulisation which has several limitations in the analyses of geological material. One of the major limitations encountered for nebulization ICP–MS is that samples are required to be in a liquid state. Although optimal methods for analyzing geological samples include minimal sample preparation and contamination coupled with maximum sample throughput, nebulization requires multi-element acid-digestion techniques which can result in incomplete dissolution of some minerals in samples (e.g. zircon, cassiterite, wolframite) or loss of certain volatile elements (e.g. boron, osmium). However, the introduction of solid material into the inductively coupled plasma mass spectrometer (ICP–MS) could avoid the certain sample preparation problems that are inherent with certain geological materials. By coupling a laser ablation (LA) unit to the ICP–MS, solids can be ablated and sampled by the laser and transported *via* the argon carrier gas to the ICP–MS for analysis. Such sampling eliminates the dissolution problems and minimizes the amount of sample handling necessary. This is especially important when analyzing samples containing hazardous material (e.g. Ni, As, Pb compounds).

ATTRIBUTES OF LASER ABLATION SAMPLE INTRODUCTION

Laser ablation sample introduction for ICP–MS has many advantages over conventional pneumatic nebulization, including minimum sample preparation and direct analyses of solid samples. LA–ICP–MS is able to routinely and rapidly analyze most elements (~92) with a sensitivity of 10 ppm. The technique also has sufficient dynamic range to determine major, minor and trace constituents in both rock pulps and individual minerals, with a precision and accuracy of about ± 5%. The standard sample cell can accommodate specimens as large as 4.5 cm in diameter and 4.0 cm in height. Sample cells of various shapes can be used to accommodate larger samples.

LA–ICP–MS results in a spectral interference common to nebulization ICP–MS (i.e. resulting from formation of oxides and hydroxide species). The plasma background spectra is also simplified when utilizing LA–ICP–MS. The laser can be focused to a beam 20 to 200 µm in diameter with good resolution which results in analytical comparable capabilities similar to an electron microprobe. Table 1 summarizes and compares LA–ICP–MS with other multi-element (ED–XRF) and electron microprobe techniques.

ELEMENTAL ANALYSES OF VARIOUS GEOLOGICAL MEDIA

The ablating capacity of the neodymium-yttrium aluminum garnet (Nd-YAG) laser is such that most geological material can be analyzed. Like the electron microprobe, LA–ICP–MS can determine elemental abundances in individual minerals and thus aid in mineral identification by providing mineral chemistry. However, LA–ICP–MS is faster, can analyse for up to 92 elements and typically has lower detection limits (10 parts per million) for most elements (see Table 1). For example, trace elements such as Rb, Cs, Ba and Ga in feldspar, and the platinum group elements (PGE) in chalcopyrite can be analysed rapidly at these levels to aid in petrogenetic interpretations.

The solid sampling technique of laser ablation also allows rock slabs to be analysed by ICP–MS. As in Energy Dispersive X-ray Fluorescence (EDXRF), LA–ICP–MS can be used to characterize mineral and rock compositions and determinate rare-earth elements (REE) in discrete minerals. Rock slab characterization can result in efficient elemental abundances reconnaissance. Based on these reconnaissance surveys, the method or elemental packages that best meet a projects needs and requirements can be selected.

Direct analysis of Ni and Pb fire assay buttons is theoretically possible by LA–ICP–MS. The advantage of button analyses is that elements such as platinum group elements and gold (Au) could be analysed quickly and the tedious acid dissolution procedures presently required for induced neutron activation analysis (INAA) and graphite furnace atomic absorption (GFAA) techniques avoided. In addition, the fire-assay technique also concentrates other "pathfinder" or "petrogenetically significant" elements such as As, Hg, Sb, Sn, W and Co. These elements can be also analysed in the fire assay button. Isotopic determinations can also be performed directly on the fire-assay button. As well, elemental and isotopic analyses of the fire-assay flux can be used to determine partitioning between the flux and button.

Table 1. Comparison of important analytical parameters of LA–ICP–MS, energy dispersive X-ray fluorescence (EDXRF) and electron-microprobe analysis.

	LA–ICP–MS	EDXRF	Electron-Microprobe
Time/analyses	5 sec.	2–5 minutes	1 minute
Trace Element Sensitivity (time dependent)	excellent	<mass 185: poor >mass 185: good	moderate
Isotopic Capability	Yes	No	No
Maximum number of elements per analysis (measured simultaneously)	92	24	8*
Spot size	20-200μm	–	1-10μm
Dynamic range	ppm-%	10ppm-%	100ppm-%
Lower detection limit per unit time	~10 ppm/30 sec	~10ppm/5 min.	100ppm/2 min.
Autosampler	restricted by sample size	yes: 16 samples	restricted by sample size
Sample Preparation Time	sec.-min.	sec-5min.	> 5min.
Calibration Technique	calibration by fundamental parameter	calibration by fundamental parameter	mineral/synthetic standards

** spectrometer dependent*

LA–ICP–MS is capable of quantitatively analyzing pressed powder briquettes. Thus, analytes which must be determined by labour intensive methods or require unique preparation procedures due to solution chemistry or refractive nature (e.g. Ba, Cr, Sn, W, Mo and Hg) can be accommodated in this form.

ISOTOPIC DETERMINATION OF GEOLOGICAL MATERIAL

LA–ICP–MS can assist with elemental and isotopic zonation in individual mineral grains. The precision of isotopic ratio determinations for geological material is about ± 0.2% for the radiogenic Re-Os, Pb-Pb and Rb-Sr isotopic systems. Stable isotopes which vary due to geological processes can also be analyzed (i.e. Ag, Cr, B, Li) thus, yielding age and petrogenetic information about the sample. Such capabilities are especially advantageous when individual mineral grains are analysed. In the past, isotopic determinations usually involved time-consuming preparation of whole-rock or mineral separates. However, with LA–ICP–MS, such preparation is less likely to be required.

QUANTIFICATION OF ELEMENTAL ABUNDANCES

Calibration and standardization of laser ablation systems has been successfully undertaken (Thompson et al. 1989; Darke et al. 1989). However, such work has been on metal and steel samples for the metallurgical industry. The best documented case of laser ablation analyses using geological materials is by Darke et al. (1989) which illustrated the importance of using closely matrix-matched samples and standards. The lack of well documented geological standards for LA–ICP–MS is a major hurdle requiring attention for any lab interested in LA–ICP–MS. Accordingly, the lack of well documented geological material for laser ablation hinders progress in this type of anlayses.

SUMMARY

The ICP-lab, Spectroscopy Subsection of Geoscience Laboratories will have a Perkin Elmer model 320 laser coupled to a Perkin Elmer/Sciex Elan 5000 ICP–MS in the Sudbury Mines and Minerals Research Facility. The accuracy, precision, detection limits, elemental coverage and speed of LA–ICP–MS analysis make it an appropriate technique for many geological applications. It is anticipated that the LA–ICP–MS will provide geologists with a new tool capable of obtaining large amounts of data from rocks and related geochemical samples.

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39. Project Unit 91–16. Mobility, Distribution and Adsorption of Heavy Metal Contaminants, Welland River, Southern Ontario. Part 1: Sampling and Analytical Method Assessment

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INTRODUCTION

High concentrations of heavy metals occur in the Great Lakes and "Golden Horseshoe" waterways (Kauss 1983; Thornley and Hamdy 1984; Mudroch 1984, 1985; Mudroch and Duncan 1986). Sediments can concentrate trace metals physically (adsorption) or chemically (composition) (Horowitz and Elrick 1987; Forstner and Wittmann 1983). Grain-size studies indicate that fine-grained material tends to accumulate large quantities of the highest concentrations of heavy metals (Kemp et al. 1976; Mudroch 1984; Mudroch and Duncan 1986; Horowitz and Elrick 1987). This accumulation has an effect on the whole food chain (Forstner and Wittmann 1983). Bottom feeders and sediment dwellers find these metals biologically available due to metal adsorption on sediment. Trace metals suspended in the water column are biologically available to suspension-feeding organisms. Thus, heavy metal contamination continues up the food chain to higher organisms. There are strong health implications for heavy metal contamination because these accumulate in all types of biological organisms (Forstner and Wittmann 1983). Thus, studies delineating such zones are timely. A joint project between the Geoscience Laboratories Section of the Ontario Geological Survey (OGS) and Brock University began in 1991.

This study focusses on one specific area located in the Welland River which is of immediate importance because of a proposed dredging project which could disturb and remove the contaminated sediments. The OGS (Geoscience Laboratories Section) is contributing to the project by assisting with the analytical-method development required for environmental sample handling and preparation. Current emphasis of this project is to learn and evaluate existing methods and revise these methods as necessary. Redesign of the laboratory facilities at Brock University was essential to allow for contamination-free metal analysis.

Other aspects of this study assess the variation in metal content in various grain-size fractions collected from the surficial sediments in the Welland River. The data have future implications for the proposed dredging of the Welland River sediments. The Welland River could potentially be dredged and the contaminated sediments removed to restore the uncontaminated environment of the river. Complications of this dredging could involve accidental remobilization of the contaminated sediment which would cause more extensive damage downstream and progressing from there into Lake Ontario.

STUDY AREA

The Welland River is located in the Niagara peninsula, south of St. Catharines, Ontario (Figure 1). The river empties into the Niagara River which then drains into Lake Ontario. The river has a high suspended-sediment load (I. Brindle, Chemistry Department, Brock University, personal communication, 1990). The underlying sediment and bedrock have an influence on the river water's acidity. The water has a relatively high pH which is a reflection of the carbonate rock comprising the local bedrock. Quaternary sediments surround and underlie the river. Atlas Specialty Steels Co. and other industrial sites are located on the Welland River. Waste effluent has been disposed of in the Welland River for approximately 60 years (Dickman et al. 1990). This portion of the river was selected as it was thought to be contaminated with heavy metals and oils. The proposed dredging project to clean up the oil and heavy metals in the sediment is expected to commence in the autumn of 1991.

METHODS

Investigation into methodology, equipment availability and applicability have resulted in the delineation of the following sampling and analytical procedure (Figure 2). This procedure has been tested and has proved optimal for the study.

Sampling and Grain-Size Analysis

Bottom-sediment samples were collected from the Welland River using a plastic shovel. Wet samples were placed in bags without draining off the water. The samples were

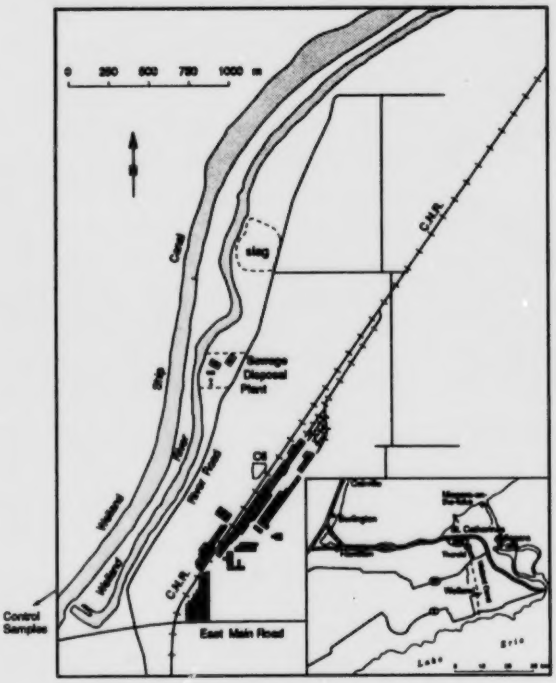
0 250 500 750 1000 m
slag
Sewage Disposal Plant
C.N.R.
Canal
River Road
Welland River
East Main Road
Control Samples
Erie
Lake

Figure 1. Sample area of the Welland River located in Welland, Niagara peninsula.

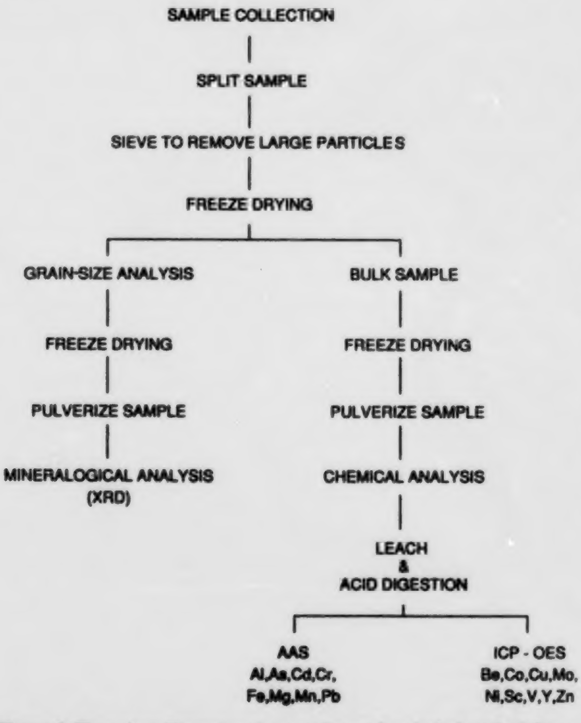
SAMPLE COLLECTION
SPLIT SAMPLE
SIEVE TO REMOVE LARGE PARTICLES
FREEZE DRYING
GRAIN-SIZE ANALYSIS
BULK SAMPLE
FREEZE DRYING
FREEZE DRYING
PULVERIZE SAMPLE
PULVERIZE SAMPLE
MINERALOGICAL ANALYSIS (XRD)
CHEMICAL ANALYSIS
LEACH & ACID DIGESTION
AAS
Al,As,Cd,Cr,
Fe,Mg,Mn,Pb
ICP - OES
Be,Co,Cu,Mo,
Ni,Sc,V,Y,Zn

Figure 2. Flow chart illustrating the sampling and analytical methodology delineated for use in this study. Abbreviations used here are defined either in the text or in Table 1.

brought to the laboratory at Brock University and stored in a deep freezer. After thawing, each sample was wet-sieved using a stainless-steel sieve to separate particle fractions less than 63 µm. This fine-grained fraction was freeze-dried. A sample weighing 1 g was separated into 5 size fractions (less than 13 µm, 13 to 23 µm, 23 to 32 µm, 32 to 45 µm and 45 to 63 µm) using a procedure developed at the Canadian Centre for Inland Waters (CCIW) in Burlington. This subsieve particle range technique separates the sediment by centrifuging the sample in individual chambers. The water is drained off and the separated fractions are freeze-dried.

Digestion Techniques

Several extraction techniques can be used to release the heavy-metal complement of each grain-size fraction. The first technique involves an acid leach of the sample, followed by washing with deionized water. This allows for analysis of the exchangeable cations (Dickman et al. 1990). The second technique—a sequential extraction procedure—is used to analyze the different chemical phases of metal uptake. The sequential analysis will determine the distribution of accumulated heavy metal on 5 chemical phases: 1) exchangeable cations, 2) carbonate phase, 3) iron and manganese oxide phases, 4) organic fraction and 5) residual fraction (Tessier et al. 1979). The technique used by Tessier et al. (1979) will be determined for only a selected number of samples because of the time involved in the technique and the number of samples becomes too great. The total extraction procedure is outlined in Geosciences Laboratory Manual procedure EA18 (OGS 1990).

Spectroscopy

Following extraction, the elements Be, Co, Cu, Mo, Ni, Sc, V, Y and Zn (Group A) will be analyzed on a JY48 Inductively Coupled Plasma-Optical Emission Spectrometer at the Geoscience Laboratories Section. The presence of Al, As, Cd, Cr, Fe, Mg, Mn and Pb (Group B) will be determined by Atomic Absorption Spectrometer using flame (FAAS) or graphite furnace (GFAAS) at Brock University (Table 1). The choice of FAAS or GFAAS is dependent upon the spectral and chemical characteristics of each element in Group B. A standard-reference material (e.g., NIST 2704) will be used in each set of analyses to determine the appropriate precision and accuracy. These elements will be determined for this study because of their health implications and environmental impact. Mineralogical analysis will be performed by X-ray diffraction (XRD).

PROGRESS AND CURRENT WORK

The research commenced during the summer of 1991. Sediment samples were collected from the Welland River, separated and freeze-dried. Analytical methods were learned, evaluated and revised where necessary at the Geoscience Laboratories Section of the Ontario Geological Survey. A set of in-house

Table 1. Elements to be analyzed by analytical methods.

Elements	Analytical Method	Site	Reference
Al	FAAS	BU	Brand 1986
As	GFAAS	BU	
Be	ICP–OES	GL	OGS Staff 90
Cd	GFAAS	BU	
Co	ICP–OES	GL	OGS Staff 90
Cr	FAAS	BU	
Cu	ICP–OES	GL	OGS Staff 90
Fe	FAAS	BU	Brand 1986
Mg	FAAS	BU	Brand 1986
Mn	FAAS	BU	Brand 1986
Mo	ICP–OES	GL	OGS Staff 90
Ni	ICP–OES	GL	OGS Staff 90
Pb	GFAAS	BU	
Sc	ICP–OES	GL	OGS Staff
V	ICP–OES	GL	OGS Staff
Y	ICP–OES	GL	OGS Staff
Zn	ICP–OES	GL	OGS Staff

FAAS: Flame Atomic Absorption Spectroscopy
GFAAS: Graphite Furnace Atomic Absorption Spectroscopy
ICP–OES: Inductively Coupled Plasma—Optical Emission Spectroscopy
GL: Geoscience Laboratories Section, Ontario Geological Survey
BU: Brock University

reference materials (MRG-1, SY-2, and BAS-55) were analyzed to learn and apply the method of total digestion. Subsequently, the procedure was established for the Brock University laboratory's FAAS. At this time, the Brock University laboratory was refitted to allow contaminant-free environmental-geochemistry research. New equipment and teflon materials were installed to ensure a safe, trace-metal-free laboratory.

PROBLEMS ENCOUNTERED

Several experiments were performed to assess the best way to separate the sample into the different grain sizes required for this study. The grain sizes separation procedure used by the OGS was inappropriate because of the use of sodium hexametaphosphate in the technique that could interfere with the trace-metal analysis and because the process does not separate the finer particle sizes below 63 µm effectively. A previous attempt at dry-sieving the samples failed. After these experiments, a technique using a Cyclosizer™ at the CCIW, which separates particles by centrifuging, was deemed most appropriate.

SUMMARY AND FURTHER WORK

Future plans include: 1) completing the grain-size analysis for all samples; 2) finalizing and completing chemical analysis of the bulk sample and leachates; 3) investigating the mineralogy of the grain-size fractions containing anomalous contents; 4) interpreting the trace-metal data, grain-size analysis and mineralogical data; and 5) predicting problems that could arise during the dredging of the sediments.

ACKNOWLEDGMENTS

The authors wish to thank B. Parkins and T. Beckett for assistance with field work, J. Terasmae for use of equipment, H. Melville for assistance in the lab and M. Lozon for drafting the illustrations. A. Mudroch and G. Duncan (Canadian Centre for Inland Waters) kindly provided training and use of the Cyclosizer. Appreciation is extended to G. Henri (Geoscience Laboratories Section, OGS) for providing guidance in the analytical methodology. D. Crabtree and H. DeSousa (Mineral Chemistry Subsection, Geoscience Laboratories Section, OGS) provided for us training in grain-size analysis. Financial support was provided by a National Science and Engineering Research Council (NSERC) Grant (7961) to U. Brand and by a grant from the Ministry of the Environment to I. Brindle.

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40. Project Unit 91–16. Quality Assurance and Quality Control Measures in the Fire Assay Laboratory

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INTRODUCTION

Over the last few years, the Geoscience Laboratories Section of the Ontario Geological Survey (OGS), in common with many other laboratories, has been placing increased emphasis on quality control procedures in order to maintain and improve the quality of the analytical data output. More recently, this has developed into a comprehensive program of Quality Assurance and Quality Control (QA-QC) which aims to encompass all aspects of the laboratories' performance. Here we report on progress in the development and application of the program in the fire assay laboratory. It is addressed to those seeking to implement quality assurance and quality control programs, particularly in small fire assay laboratories which serve the minerals industry.

The Mineral Sciences Subsection's fire assay laboratory deals with many different types of samples from a variety of clients which range from OGS geologists to prospectors. On occasion, it also carries out assays in legal cases and umpire assays. The aim of the QA-QC program is, firstly, to demonstrate to all the users that the data they have received is of the quality stated in the Analytical Capabilities booklet. Secondly, the program ensures that the same level of quality is being achieved for every analysis.

Implementation of QA-QC programs is particularly important in the analysis of precious metals. However, this is not altogether a recent concern as sixteenth-century assayers paid equal attention to QA-QC in fire assay methods to ensure that the quality of their data was high (van Loon and Barefoot 1989).

QUALITY ASSURANCE FRAMEWORK IN THE LABORATORIES

In this section, we shall consider very briefly the components of a quality assurance program (Dux 1986), which are discussed here under three headings: the laboratory, the personnel, and the methods and equipment. The object of this is to make clients aware that the generation of high-quality data is not just a question of methods and equipment. As S. Abbey (Geological Survey of Canada, personal communication, 1990) once remarked, if you want high quality results, who does it is as important as how it is done. The quality assurance program aims to inform clients as to who has done the work and how well it was done by documenting all aspects of a fire assay laboratory's operation.

The mandate and purpose of the laboratory should be clearly stated so that everybody involved—analysts, management and clients—knows what is expected of the laboratory. The fire assay laboratory's purpose is to supply assays for precious metals (Au, Ag, Pt, Pd) using the lead fire assay technique, and also to investigate techniques such as NiS and Cu_2S collection for Au and platinum group elements (PGE). The determination limits and precision expected must be defined (*see* below). Up-to-date plans of the laboratory and services (power, water) should be available for consultation by all. With the introduction of electronic devices, such as computers and electronic balances, analysts need to be aware of possible physical and/or electronic interferences and have recourse to the plans for solution to any problems that occur.

Another aspect of the laboratory that is important is that the organizational structure, reporting relationships and qualifications of all personnel should be documented. Analysts must know who to report problems to and clients must be assured that adequately qualified personnel are available to do the job. Ongoing training of staff to keep pace with technological and scientific changes is an integral part of the quality assurance policy.

The role of the laboratory personnel in a QA program must be properly understood and clearly defined. The laboratory manager, the data manager and the analysts must cooperate in ensuring that quality practices are adopted and working. The responsibility of the laboratory manager is to formulate the QA program, allocate sufficient resources for its operation and monitor QC, thereby assuring that the system is working properly. The data manager receives samples from clients and transmits data back; this person is also responsible for tracking samples and inserting reference materials and blind duplicates into sample batches.

For the analysts, the QA program can be regarded as the process which provides the evidence that they are doing a good job. This is done by keeping detailed records of all that is done in the laboratory: which samples were analyzed, when, by what method and other relevant observations. These are noted in the analyst's log book. Should problems arise later, their identification is made much easier as the records can be consulted as to how the work was carried out. The analysts are also responsible for signing off on all completed analytical work performed. The laboratory manager also signs off on the data after assessing the QC information. It should be noted that the number of people involved in these tasks will vary according to the size of the laboratory; small operations may only require 1 person to combine many or all of these roles.

The quality assurance program dictates the frequency at which instruments are serviced and how and when they are calibrated. This information is noted in instrument logs, along with any problems that may arise. An important part of the quality assurance program is the methods manual (e.g., OGS 1990). It ensures that a standard method is followed by all and that no variations are permitted. The extent of the quality control required depends entirely on the method being used as discussed below for the fire assay laboratory.

SPECIFIC QUALITY CONTROL MEASURES

The individual quality control measures that have been introduced in the fire assay laboratory have arisen from evaluation of what processes can be controlled in the fire assay method. The procedures used in the fire assay method are shown in Figure 1. We have evaluated each procedure carefully and devised appropriate quality control measures in order reduce or eliminate as many sources of error as possible.

Sampling

Sampling of rocks may not be thought of as a laboratory quality control concern. However, unless a representative sample has been collected, all the precautions and analytical rigour undertaken by the laboratory become meaningless. Therefore, those submitting rock samples for assaying should ensure that proper attention has been paid to sampling, as discussed, for example, by Lightfoot and Riddle (1990).

Comminution

Comminution is another step in the procedure where errors, if they occur, will not be picked up through the use of reference materials. Three major sources of error may arise in this area: misidentification of samples, contamination, and inappropriate subsampling procedures. Checks on proper sample identification are carried out when the samples are received by the Geoscience Laboratories Section as well as when the grinding-room technician prepares the samples for crushing. With the implementation of the Laboratory Information Management System (LIMS), additional checks are necessary to ensure that the labels printed by the system for the pulps correspond to both the sample list and the label on the bag submitted by the geologist.

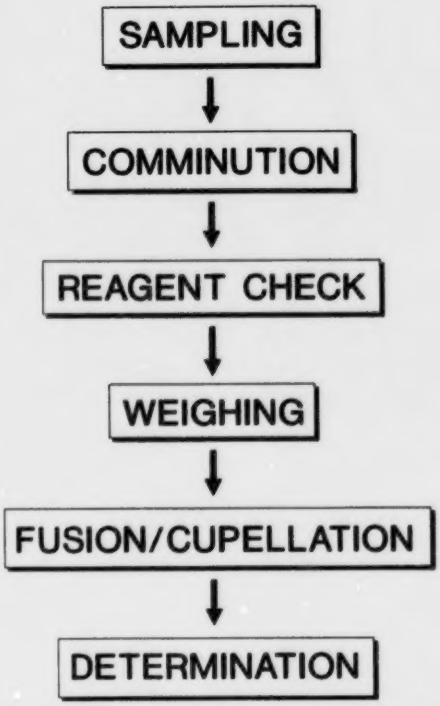


Figure 1. Procedures identified in the fire assay method where QC measures are required.

Cross-contamination during the comminution process is always a problem, because gold particles for example, are easily smeared on the surface of the jaw crusher plates and the chrome steel rings used for pulverization. Certain basic precautions can be taken, like arranging the order of the samples, so that the most mineralized ones are processed last, and keeping a record of the order and the number of the container, so that if contamination should occur then it can be easily identified. This requires that grinding-room personnel be able to identify the mineralized samples; however, this may not always be possible, particularly when staff turnover rates are high. Recruiting staff with some basic geological knowledge to work in this area is not always easy. The problems here also highlight the importance of training within the context of the quality assurance plan.

In recognizing that the occurrence of cross-contamination at this stage is a major concern, we have introduced a quality control procedure to monitor the degree of cross-contamination, by running a quartzite grinding blank. This is further discussed in the section on reference materials for quality control.

Representative samples submitted by geologists can weigh many kilograms. It is the responsibility of the Laboratories to ensure that a representative subsample of about 100 g is prepared from this. Much has been written about sampling and its effects on both analytical accuracy and precision (e.g., Gy 1979; Merks 1985). A key point in obtaining a representative sample is that the crushed rock should be sufficiently fine and well mixed before the split is taken. This is usually carried out using a riffle following the jaw crushing stage for reasons of efficiency and practicality.

By using a Fritsch jaw crusher with the jaws set at the minimum distance, we obtain a sample with a particle size of less than 1 mm, considerably finer than previously obtained with other jaw crushers. The use of flat-faced jaw plates results in an evenly sized output and also allows the jaws to be more easily cleaned. However, when large chunks are submitted, preliminary crushing of the sample is necessary using another jaw crusher, but this is offset by the reduced time required for pulverization in the ring mill. Reducing the time required for pulverization has a further advantage in that the degree of smearing of precious metals is correspondingly reduced. Moreover, the pulverizer rings do not get as hot, thereby lessening the oxidation effects on sulphides which would otherwise affect the accuracy of the determination of metals such as Cu, Pb and Zn because of the weight change involved. It is also important that the operator be trained in the proper use of the Jones riffle (Merks 1985), which is the most widely used riffle in sample preparation laboratories. The sample should be spread evenly over the full face of the sample-splitting device.

Reagent Check

Generally, the monitoring of reagents through the use of blanks within a particular sample batch is sufficient for most analytical procedures. However, the unpredictable nature of the fire assay fusion can lead to the possible contamination of reagent blanks through boil-over occurrences and spills. To determine whether or not reagents are clean requires some additional QC checks.

Our policy is that every new batch of fire assay flux is subjected to 5 blank determinations for Au, Pt and Pd. The blanks are prepared in the normal way with the addition of a silver nitrate inquart and are fused in a furnace isolated from samples. In the past, we have been able to identify impure batches of flux before they were actually used with samples, consequently having saved both time and resources.

The results for the most recent batch of Au-reagent blanks are shown in Figure 2. The distribution of the data reflects the somewhat erratic levels of gold in the fire assay flux. This distribution is used to place constraints on the determination limit for the method (determination limit equals three times the standard deviation of the reagent blank value). Our QC program involves monitoring the distribution of this data in the vicinity of the +2 standard deviation (sd) and +3 sd markers which represent the upper-warning and upper-control limits, respectively. Blanks which fall above the upper-warning limit indicate that a potential problem exists. Those which fall above the upper-control limit indicate either impure flux or contamination during fusion, thereby warranting further investigation.

Although palladium (Pd) has a somewhat similar distribution to that shown in Figure 2, we have yet to return a given lot of fire assay flux to the supplier due to elevated levels of this element. The levels of platium (Pt) and silver (Ag) in the fire assay flux are uniformly low (relative to instrumental limitations) and are therefore not shown.

Weighing

In a laboratory where we routinely switch from 10.000 g in a geochemical (ppb) determination to 14.584 g or 29.168 g for routine (ppm) samples, doubt sometimes arises as to whether previous weighings were correct. To alleviate these problems, we now use automated data capture by way of a PC laptop and the program "Balance Talk" connected to an electronic

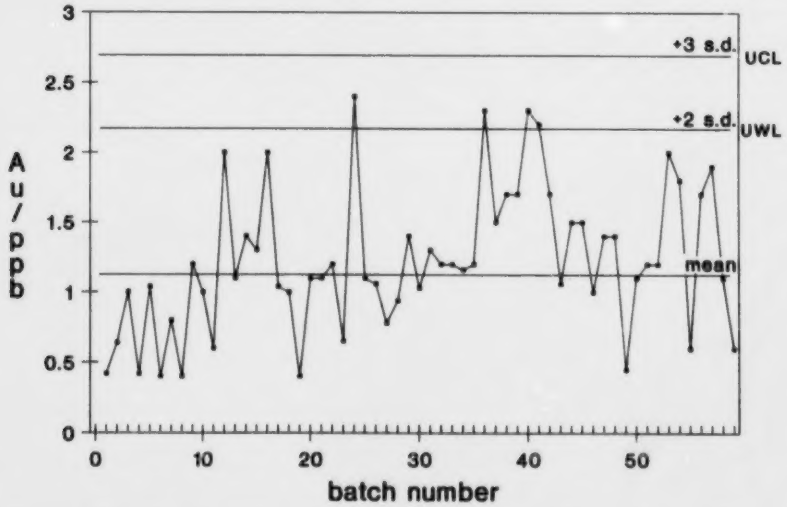


Figure 2. Shewhart quality control chart for Au in fire assay reagent blanks,. Data reported here represents determinations carried out between September, 1990, and September, 1991. UCL represents the upper-control limit; UWL, the upper-warning limit.

balance. The advantage of this control is that tare weights and sample weights are directly recorded on the computer, and the chance for human error is significantly reduced.

New microprocessor technology applied to balances is making a large contribution to reducing laboratory errors and adding to quality assurance. In fact, many of the recent innovations in balances arise directly from the need for better QC in laboratories. Features such as automatic recalibration in response to changes in ambient conditions result in more reliable weighing, particularly for microbalances. This is very important in the fire assay laboratory as the key measurements in the gravimetric procedure both involve weighing; namely, the amount of pulp prior to fusion, and the resulting prill following cupellation and parting. By automatically capturing these data into a spreadsheet-type program like "Balance Talk", the final calculation can also be carried out automatically. The net result is the elimination of errors associated with transcription and calculation of data and a reduction in the errors traditionally associated with weighing.

As a further guarantee that balances are functioning properly, we check the balances on a daily basis using National Bureau of Standards (NBS) class S calibration weights. These quality control checks are recorded on the computerized job work sheet which serves as a record in the Geoscience Laboratories Section's quality assurance program.

Rolling the sample on a rubber mat or on glazed paper prior to weighing is also necessary to reduce mineral segregation. This process begins as soon as the sample is loaded into the bag after pulverization because of the differing physical properties of the minerals comprising the sample. All analysts, especially those without geological training, should be made aware of this. It is common to find analysts who assume that finely ground geological samples are homogenous, when in fact segregation processes occur every time the sample is subject to movement.

Fusion—Cupellation

This is probably the most difficult area to implement QA-QC measures due to the inherent "dirty" nature of the procedure. Boil-over occurrences in the furnace are not uncommon and difficult to overcome as it is not easy to anticipate the chemistry of the sample and to adjust the flux mixture accordingly. Therefore, as in the comminution procedure, contamination is always a potential problem. The only way to evaluate contamination is to record the direction of boil-over occurrences on the job work sheet. We have been successful in identifying cases where high gold concentration samples have contaminated neighbouring samples with levels of gold which should have been below the detection limit (less than 2 ppb). These samples are identified, rerun and then resubmitted for determination. In the future, it should be possible to rapidly screen all samples using energy-dispersive x-ray fluorescence techniques and adjust the flux mixture where samples with complex compositions are identified.

Another important concern is that of maintaining temperature in the assay furnaces. Furnace temperatures are measured using an optical pyrometer, and values are recorded in equipment logs on a weekly basis. It may be argued that any fluctuation in temperature which could have a detrimental affect on the collection of precious metals will be reflected in the values recorded for the reference materials. This may be true, but we cannot assume that all samples have similar compositions to those of the reference materials. This is particularly true for samples with elevated levels of refractory minerals.

In addition, there are a lack of reference materials available to match the range of samples commonly run, and they aren't available in the quantities necessary for fire assay determination. Such deficiencies need to be addressed through the development of in-house standards as suggested by Johnson (1990).

Fire assay technicians are also required to record the size of the recovered lead button and also to note any interferences which may be imparted by sulphides, base metals, refractory minerals or other components. Those samples which pose doubt may require major element determination or XRD analysis to aid in resolving the most complex fusion problems.

The most common problem we have encountered during the cupellation process is confusion with respect to the orientation of cupels following removal from the furnace. To overcome this we require a row of blank cupels to be placed behind the sample batch. These cupels act as shields to maintain the temperature of cupels which are closest to the furnace door as well as a reminder to the technician of which sample is the first and last in a series or sample batch.

The final QC step with regard to this procedure involves the recycling of fusion crucibles. How can we assure that a crucible used for several fusions does not contain residues of precious metals from a previous sample? The way we have approached this problem is to check for carry-over in a number of crucibles which carried high levels of precious metals. Even though the results were somewhat erratic, we were able to conclude with confidence that carry-over does not exist for samples which contain less than 4 ppm Au, Pt or Pd. As a safeguard, we discard any crucibles which gave values of more than 1 ppm of either Au, Pt or Pd.

After every fusion is completed, the crucibles are placed on a recycling shelf with a copy of the job sheet attached. Following determination, those crucibles which do not comply with the above mentioned criteria are discarded.

Determination

Control measures applied to this procedure depend to a large extent on how the determination is carried out. The Geoscience Laboratories Section has two procedures for the determination of precious metals. The first is a gravimetric method for the determination of Au (detection limit of 0.01 ounce per ton or 0.34 ppm) and Ag (detection limit of 0.10 ounce per ton or 3.4 ppm). The other involves the determination of Au (detection limit of 2 ppb), Pt (detection limit of 1 ppb) and Pd (detection limit of 1 ppb) concentrations by graphite furnace atomic absorbtion spectroscopy (GFAAS). Quality control measures for the gravimetric determination have been discussed in a preceding section under "Weighing". Additional QC measures involve the use of a number of in-house standards to monitor the recovery of Au and Ag. Other QC steps that could be incorporated in the future include control of the reagents used in parting and ensuring that the annealing process can be reproduced, possibly through the use of a programmable furnace. Quality assurance measures used in the GFAAS measurement have been discussed previously (Crabtree et al. 1990). They require that a total of 2 reagent blanks and 1 standard be processed for a maximum sample batch of 20. Instrument recalibration is performed following every 10 samples.

Following determination by both the gravimetric procedure and GFAAS, data is transferred to the LIMS where QC charts for standards and reagent blanks are automatically constructed. It is here that the analyst can check their work prior to reporting the data. Once the data is reported, the supervisor, data manager and others charged with monitoring quality control can decide if the defined limits of precision and accuracy have been maintained.

CHOICE OF REFERENCE MATERIALS IN THE QUALITY CONTROL PROGRAM

The role of reference materials in a geochemical and assay laboratory has been summarized recently by Johnson (1990). Because of the large sample weights used in fire assay techniques, it is inadvisable to use certified reference materials on a regular basis. Not only would the cost be prohibitive, but these materials are not usually available in large quantities. Thus, the use of standards developed in-house then becomes essential.

The Geoscience Laboratories have had a successful program for developing in-house standards for many years. For example, concentration values for Au and Ag in the MRB-25 in-house standard were compiled through a round robin program. This data was then used to establish both a mean and a relative standard deviation. Figures 3a and 3b illustrate the distribution of Au and Ag values, respectively, for this standard over the last 45 batches of samples. Data for both elements (apart from 1 point in Figure 3a) fall within the upper- and lower-warning limits and indicate that the analytical system during this period has been well controlled. Reagent quality is of less concern here due the relatively high detection limits. On occasion, certified reference materials, such as MA-2A, MA-2B and MA-3, will be incorporated into a batch of these samples to check for consistency.

At present, we do not have a low concentration Au in-house standard which could be used for the GFAAS work. As a result, we must make use of charges which have been spiked with solution standards until an acceptable in-house standard reference material can be developed.

As discussed above, the comminution process can introduce significant contamination into samples. This occurs during the crushing and pulverization process when heating effects caused by friction can smear malleable gold, silver and other noble metals into crevices and cracks of the grinding media. This is difficult to remove by either wire brushing or the use of compressed air, while quartz-sand washes are not normally used for reasons of efficiency. Ordering of samples does reduce the chances of cross- contamination, but the intermittent use of quartzite during comminution can demonstrate to all concerned whether or not any contamination has occurred.

Thus the regular use of quartzite in our QC program can also be viewed as an application of reference materials for quality control. It is perhaps the only way that proper monitoring of the comminution process and the efficiency of cleaning between samples can be carried out. Proper selection of the quartzite (in this case, Unimin in Midland, Ontario) can ensure a material that is practically free of all elements that need to be monitored. In addition, the abrasive nature of quartzite will ensure thorough scouring of the surfaces of the grinding media so that we are always looking at a "worse-case scenario" when monitoring the quartzite data.

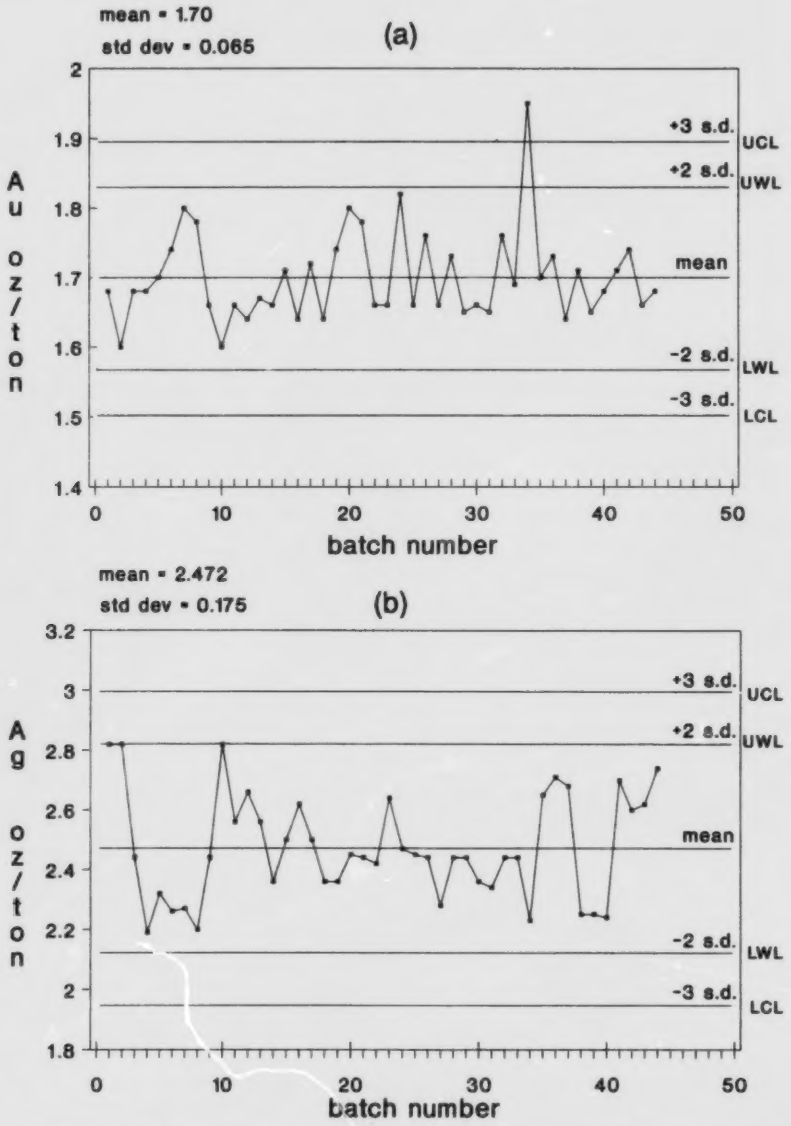
The results for Au, Pt and Pd are presented in Figure 4. This data was collected over a 1 year period, from the initiation of the quartzite control project to the present time. The data indicate that very little cross-contamination has occurred during the period from September, 1990, to September, 1991. For almost all of the spikes that appear, we have been able to identify a high (greater than 1 ppm) Au- or Pd-bearing series of samples which preceded the quartzite blank during comminution.

The program has been successful in identifying where problems may occur and where particular samples should be flagged for resubmission. Once a problem has been identified, corrective actions, such as rerunning or reprocessing the samples, can be taken. As a result, we are now able to monitor the entire process—beginning with comminution and ending with determination—with confidence.

CONCLUSIONS

The establishment of a QA-QC program is not something that occurs in a short period of time, particularly in laboratories with a large workload. Quality control measures can be introduced only after a thorough analysis of procedures used and an appreciation of possible sources of error.

Our experience has shown that once a reasonable body of quality control data has accumulated, problems in the method can be pinpointed. In solving these problems, it may be become apparent that certain information are not being



Figures 3a and 3b. a) Shewart quality control chart for Au in-house standard MRB–25. b) Control chart for Ag in-house standard. Data reported here represent determinations made during the period from September, 1990, to September, 1991. UCL represents the upper-control limit; UWL, the upper-warning limit; LWL, the Lower-warning limit, and LCL, the loser-control limit.

recorded in the quality assurance documentation and/or that additional quality control measures need to be implemented. Thus, the process becomes one of continual and incremental change. This program should therefore allow for frequent updating of the methods and quality assurance documentation.

It may be argued that the amount of documentation and additional testing required by a QA-QC program will have a negative effect on productivity, and this may be true initially. However, once the system is in place, further changes will only occur gradually. Also, developments in laboratory technology (such as LIMS and document-archiving systems) will make it easier to keep track of the documentation required. The payoff is long-term as clients return with further work because of the high quality of the work, while for the staff, the program provides documentary evidence that they are doing a good job, with resultant job satisfaction.

ACKNOWLEDGMENTS

A number of Geoscience Laboratories Section staff members (past and present) have contributed towards the implementation of a QA- QC program in the fire assay laboratory. They

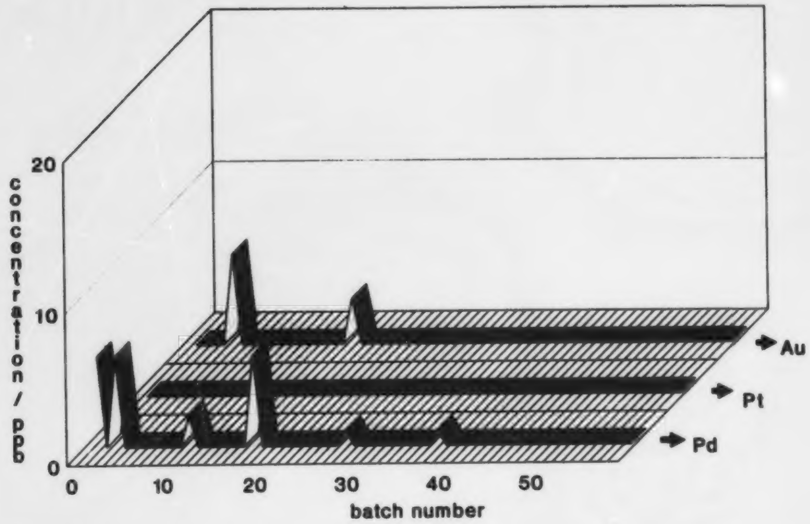


Figure 4. Levels of Au, Pt and Pd in comminution blanks observed for the period from September, 1990, to September, 1991.

include R. Ahmadian, M. Ghobrial, A. Laine and T. Hodges. We would also like to acknowledge Unimin of Midland for providing the quartzite rock used in the QA-QC program.

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41. Project 90–16. Developments in Geoanalytical Inductively Coupled Plasma Mass Spectrometry

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INTRODUCTION

In principle, inductively coupled plasma mass spectrometry (ICP–MS) is expected to provide analytical capabilities which would be of particular interest for geoanalytical work (Riddle et al. 1988). In practice, considerable development work has been required to circumvent or minimize the analytical difficulties encountered with geoanalytical ICP–MS. Previous experimental work completed at the Ontario Geological Survey (OGS) identified 3 problem areas which were particularily severe: 1) determinate (nonrandom) errors associated with inter-element effects, 2) engineering design problems with the supersonic inlet, and 3) solution chemistry.

Successful resolution of the problems at the OGS has either provided new capabilities or extended the existing analytical services provided by ICP–MS. Table 1 summarizes the improved analytical figures of merit in the context of their significance to geological studies that have used the ICP–MS data. This report will present the primary analytical and spectroscopic findings of this work.

CHEMISTRY

Solution Chemistry

As part of the quality-control procedures developed in the ICP laboratory, reference materials must be analyzed with every batch of samples. Preparations of the better-characterized (but scarcer) reference materials, such as the USGS basalt reference material BCR-1, will be analyzed less often. Consequently, a single preparation of a reference material may be in use for months.

Solution stability over time is an important consideration for the hydrofluoric acid stabilization procedure developed during this project (Doherty et al. 1990). A key step in this procedure is the addition of a small amount of hydrofluoric (HF) acid to the final solution. The HF is thought to produce solvated fluoride complexes of Zr, Hf, Ta and Nb. It was necessary to verify that a) the soluble fluoride complexes are stable, and b) the rare earth element (REE) and other analytes are not precipitated as insoluble fluorides.

Solutions prepared in September, 1989, were stored, and the analyte concentrations redetermined in December, 1990. For the range of reference materials examined (gabbro, basalt, syenite and granite), solution stability did not appear to be a problem for the method; all of the data were within ±7% of their original value. The BCR-1 data (Table 2) are a representative example of the accuracy and long-term stability of the solution work.

Reduction of Sample-Preparation Time

It takes 3 days to produce a rock solution for analysis (OGS 1990). A preliminary investigation showed that a 33% reduction in the sample preparation time was feasible and the work was assigned as a thesis project (Duong 1991). Once a week over a 7 week period, reference materials were prepared using the 2 day digestion procedure. The solutions were then analyzed for Y, the REE, Rb, Cs, Sr, Zr, Nb, Hf and Ta using the method described by Doherty et al. (1990). For the range of rock types included in this study (gabbro, basalts, syenites and granites) there was no significant degradation in the accuracy or precision of Rb, Sr, Zr, Cs, Nb, Hf and Ta determinations due to the reduction in digestion time (Duong 1991). The chondrite plots for gabbro reference material MRG–1 and the in-house basalt reference material MRB-29 are shown in Figure 1 for the 1989 data set and the 2 day digestion data. The good reproducibility of the method combined with the high precision permits modelling of geological processes when discrimination between the alternative models relies on small chemical variations (e.g., *see* Lightfoot et al. 1990)

Elemental Coverage

The instrument calibration techniques which were applied to the determination of Y, the lanthanides, Hf, Nb, Ta, Zr, Rb, Cs and Sr are being extended to cover the determination of Rh, Ir, Pt, Pd, Au, In, Bi, Tl, Pb, Th and U. In the case of In, Pb, Tl, Th and U, the solutions prepared for Y and REE determinations are being used. A method for the trace and ultra-trace determination of the precious metal is currently in progress.

The recent (October, 1991) installation of a sub-boiling distillation unit will produce concentrated hydrofluoric acid with reduced levels of Zr, Hf, Ta and Pb contamination. This will improve the precision and accuracy of determinations at very low levels (less than 0.1 ppm in the rock) in both whole-rock samples and mineral-separates. For a geological application of this type of work, which uses the ICP–MS REE data for whole-rock and mineral-separates samples, refer to Sutcliffe et al. (1990).

Table 1. Analytical figures of merit and their impact on geological work.

Precision (2%–4% rsd)	Modelling of contamination sources and processes occurring during continental flood basalt formation and Cu-Ni ore formation requires detection of very small variations in the trace level elemental concentrations. *See* Lightfoot et al. (1991), Lightfoot et al. (1990); Naldrett et al. (in prep.) as example applications of the ICP-MS methods developed at the OGS.
Accuracy (within ±5%)	Nonspectroscopic interferences can affect accuracy so that trends in trace element data reflect the dependence of the analyte signal on the concentration levels of a concomitant element such as Ti or Ca. Failure to compensate for these effects will lead to incorrect geological interpretations of the data.
Reproducibility	Long-term projects require analytical methods which can reliably provide an internally consistent chemical database.
Detection Limits (ng g^{-1})	Improved instrument detection limits permit determinations on mineral separates as well as whole rock samples (*see* Sutcliffe et al. 1990 for an application example) The low detection limits have also found application to the determination of REE distribution coefficients between fluids and magmas thus, (Gorbachev and Doherty, unpublished data).
Elemental Coverage (33 elements from ^{85}Rb to ^{238}U)	The following elements can be determined down to 0.05 ppm in the rock using a single sample preparation: Y, Sr, Rb, Cs, Nb, Zr, Hf, Ta, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu. Current research will extend this list to include: In, Bi, Pb, Tl, Th, U, Au, Pt, Pd, Ir and Rh. There are no other analytical techniques which can provide as accurate, precise and reproducible data for as many elements without considerable sample pretreatment.
Instrument Design	Studies into the physics of the supersonic inlet have produced improvements in the instrument design (Doherty 1990). These improvements have enabled development of the analytical capabilities described in the above table entries.

Table 2. Analytical data (in ppm) for the USGS basalt reference material, BCR–1. The compilation data was taken from Gladney and Burns (1983). The 1989 ICP-MS data set represent the average of triplicate analysis of three aliquots of the material. The same solutions were reanalyzed 15 months later (1990 data set). Precision values are ±1 standard deviation.

ELEMENT	ICP–MS (1989 data set)	ICP–MS (1990 data set)	Compilation
Rb	48.1 ±1.2	46.2 ±0.7	47.1 ±0.6
Sr	333 ±8	327 ±9	330 ±5
Zr	196 ±6	186 ±5	191 ±5
Nb	13.1 ±0.3	12.8 ±0.3	13.5 ±2.7
Cs	0.94 ±0.02	0.97 ±0.01	0.97 ±0.13
Hf	5.1 ±0.2	5.16 ±0.05	4.95 ±0.28
Ta	0.83 ±0.02	0.825 ±0.008	0.79 ±0.09
Y	33.2 ±0.8	31.6 ±0.6	38.7 ±6.6
La	25.0 ±0.3	24.6 ±0.6	25.0 ±0.8
Ce	55.3 ±1.6	53.7 ±0.6	53.7 ±0.8
Pr	6.73 ±0.10	6.50 ±0.03	6.87 ±0.56
Nd	28.8 ±0.5	28.0 ±0.2	28.7 ±0.6
Sm	6.73 ±0.12	6.54 ±0.07	6.58 ±0.17
Eu	2.01 ±0.05	1.986 ±0.002	1.96 ±0.05
Gd	6.55 ±0.10	6.2 ±0.1	6.68 ±0.13
Tb	1.00 ±0.03	0.98 ±0.03	1.05 ±0.09
Dy	6.3 ±0.3	6.15 ±0.04	6.35 ±0.12
Ho	1.29 ±0.03	1.21 ±0.04	1.25 ±0.14
Er	3.53 ±0.10	3.28 ±0.08	3.61 ±0.09
Tm	0.517 ±0.009	0.50 ±0.01	0.576 ±0.060
Yb	3.28 ±0.06	3.27 ±0.06	3.39 ±0.08
Lu	0.49 ±0.02	0.48 ±0.02	0.512 ±0.025

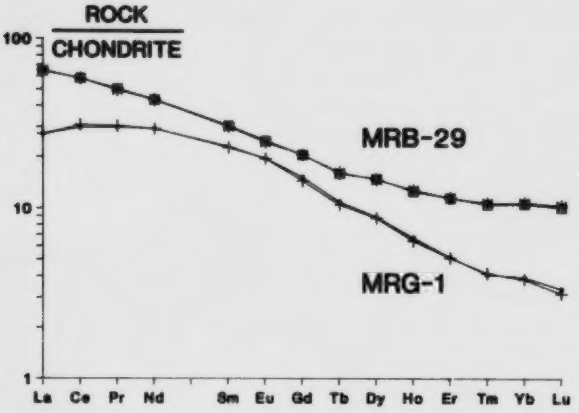

Figure 1. Chondrite normalized data for the gabbro (MRG–1) and basalt (MRB–29) reference materials prepared using different digestion techniques.

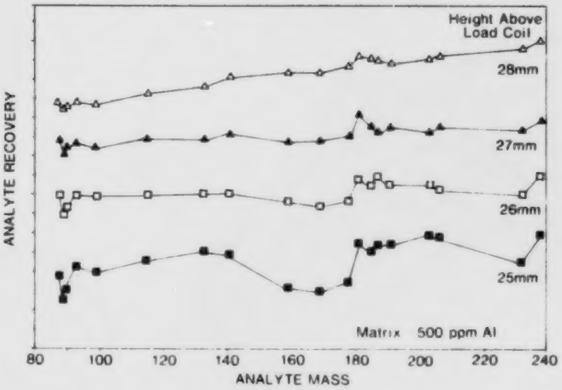

Figure 2. The effect of the load coil to interface plate spacing (equivalent to "height above the load coil") on the analyte recovery. The curves have been offset for the sake of clear presentation.

NONSPECTROSCOPIC INTERFERENCES

Elemental Analysis

A streamlined version of the Ru-Re internal standardization procedure (Doherty 1989) has been developed into a rapid diagnostic procedure suitable for use during method development and as part of the final checkout procedures for the instrument at the factory. If signal recovery (defined as the ratio of analyte signals measured in absence and presence of a matrix element) is plotted against the analyte mass, deviations from the established response characteristics can be quickly and easily detected and monitored.

The first application of this diagnostic procedure was to the investigation of the degradation in accuracy as a function of the distance between the ICP load coil and the ICP mass spectrometer interface plate. In the presence of 500 ppm Al, the mass-dependent trends (linear or nonlinear) in the determinate error were observed to be sensitive to the spacing between the load coil and the interface plate (Figure 2). The nonlinear trends are not unique to the OGS instrument (e.g., *see* Hall et al. 1990, Figure 2) and the mechanism for the effect is not at all understood. It is suspected that there is an electrical interference that is distorting the ion-extraction and ion-transmission characteristics of the instrument.

While it is preferable to run the instrument at conditions which yield linear trends, a trade-off must be made against the instrument's detection limits. Correction techniques appropriate for the nonlinear cases (where the detection limits are better) have been developed and are now being evaluated.

Isotope Ratio Work

The data from elemental analysis work implies some portion of the determinate error associated with a measured isotope ratio will be due to the processes causing the mass-dependent signal attenuation. This source of error has been observed during the determination of boron-isotope ratios in the presence of excess sodium (Gregoire 1987). As a general rule, if ICP–MS is used for isotopic determinations (e.g., Re and Os, B) in the presence of even a few hundred parts-per-million concentration of a concomitant element, then the bias associated with a signal due to mass-dependent, nonspectroscopic interferences should be evaluated. A dual internal standardization procedure analogous to the Ru-Re scheme used in elemental determinations is now being assessed for application to isotope ratio work.

FUNDAMENTAL STUDIES

The ICP mass spectrometer can be broken down into 3 major subsystems: the plasma, the supersonic inlet and the quadrupole-detection assembly. The atmospheric pressure (760 torr) plasma is drawn through a 1 mm orifice into an expansion chamber (5 torr) where the supersonically expanding plasma adjusts to the pressure conditions in the interface by forming a characteristic three-dimensional shock system referred to as the Mach cell. A conical skimmer with a 0.9 mm orifice is inserted into the Mach cell, and the plasma is extracted through the skimmer orifice into the mass spectrometer (10^{-6} torr).

While the physics of the individual subsystems of ICP mass spectrometers are reasonably well understood, there are few published reports on the ion-extraction and ion-transmission processes in the ICP–MS interface. In addition, much of that work does not directly apply to the Sciex instrument because of the absence of the radio frequency (rf) arc to ground at the sampler in their instrument. At the OGS, investigations into the fluid mechanics and the mechanical design and geometry of the interface region have resulted in improved analytical performance and reliability (Doherty 1990).

The major findings of this study include the following:

1. Nonaerodynamic skimmer designs can be used with a significant improvement in short- and long-term analytical performance and reliability. A similar design has been adopted by the instrument manufacturer.

2. Optimization of the interface geometry has increased instrument sensitivity (cps/ppb) by up to 70%.

3. The operating characteristics of the nonaerodynamic skimmers (relative to the "ideal" knife-edge skimmer) were consistent with gas dynamic theory: the beam currents were attenuated and the kinetic energy distributions of the skimmed ion beams were wider (2.4 eV versus 2.8 eV).

4. Measurements of the total skimmed beam current sampled from within the Mach cell provide enough information to calculate the macroscopic flow properties (e.g., ion density, flow speed and the gas kinetic temperature). An independent measure of the kinetic temperature of the plasma was available and served as a check on the model calculations.

5. The one-dimensional isentropic flow equations were found to be a reasonable first approximation to the ion flow dynamics and were used to calculate macroscopic flow properties in the subsonic and supersonic flows.

6. Model calculations have shown the temperature and velocity gradients in the plasma (caused by the sampler action) are unlikely to affect the ion density because the ion-neutralization reactions cannot proceed fast enough to adjust to the changing flow conditions. This result was verified by the good agreement between the calculated and measured plasma kinetic temperatures (4400°K versus 4950°K).

Future work in this area will focus on plasma flow models which can be used to obtain at least a qualitative estimate of 1) ion trajectories through the interface and the ion lenses, 2) the influence of electric and magnetic fields on ion trajectories through the interface, 3) the dominant ion-neutralization pathways and their recombination coefficients and 4) aerosol desolvation and transport processes in the plasma and the Mach cell.

SUMMARY

The anticipated elemental coverage upon completion of the ICP–MS analytical work will include the following: Rb, Sr, Zr, Nb, Hf, Ta, Th, U, Pb, Tl, Y, the naturally occurring lanthanides, Au, Pt, Pd, Ir, Rh, Cs, In and Bi. Extrapolating from previous performance benchmarks, all of these determinations will be expected to have an accuracy of ±5% and a long-term precision of less than ±5% rsd.

Work on the physics of the supersonic inlet has produced a practical, cost-saving skimmer design. Optimization of the interface geometry resulted in an improvement in instrument sensitivity of up to 70%. Future work will concentrate on the estimation of ion trajectories and transmission through the supersonic inlet and the ion lenses.

A rapid and simple diagnostic technique has been developed which is suitable both for method development and as a checkout procedure during the final-manufacturing stages of new instruments. The technique is applicable to the new generation of ICP mass spectrometers which are planned for the Sudbury facility.

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42. Project Unit 90–16. Developments in Geoanalytical Inductively Coupled Plasma Optical Emission Spectrometry

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INTRODUCTION

Several years experience in this laboratory with the more common inductively coupled plasma optical emission spectrometry (ICP–OES) methodologies has shown them to be inappropriate for Ontario Geological Survey (OGS) geoanalytical work. The day-to-day reliability of the methods was unacceptable; accuracy and precision were sensitive to small, uncontrollable changes in the plasma operating conditions. In 1987, work was begun reoptimizing the operating conditions and analytical protocols to improve the reliability of the base metals package (Cu, Co, Ni, Zn, Be, Sc, Y, V and Sr) offered to the OGS client group.

This report will summarize the experimental work which was undertaken to improve the data quality (i.e., accuracy, precision and reliability). The bench level techniques and instrument-operating procedures can be found in the laboratory manual (OGS 1990).

SIGNAL DEFINITION

Two background correction schemes were investigated: 1) the accepted analytical practice of measuring the samples' background emission signal at predefined offsets from the analyte line centre; and 2) an "IEC" (inter-element correction) scheme which treats background shifting as a form of spectral overlap.

Appropriate background positions required by the line-offset scheme were established from a detailed examination of the spectra for a range of rock types (gabbros to granites). It was determined that a minimum of 7 peak offsets were required. The total signal integration time per sample was 120 s. The IEC correction factors were determined by observing the change in background signal as a function of the concomitant concentration. The total signal integration time for the IEC scheme is 15 s per sample.

If the line offset scheme is taken to be producing the correct answer, then the data in Figure 1 shows that the IEC correction can be used without introducing significant analytical bias. This is fortunate because of the markedly smaller signal integration times required for the IEC procedure. The IEC procedure was used in all of the other work presented in this report.

LONG-TERM PRECISION

It had been noticed by us that the argon flow through the torch was noisy. Swagelok pressure fittings for the plasma and nebulizer argon gas lines, supplied with the instrument when

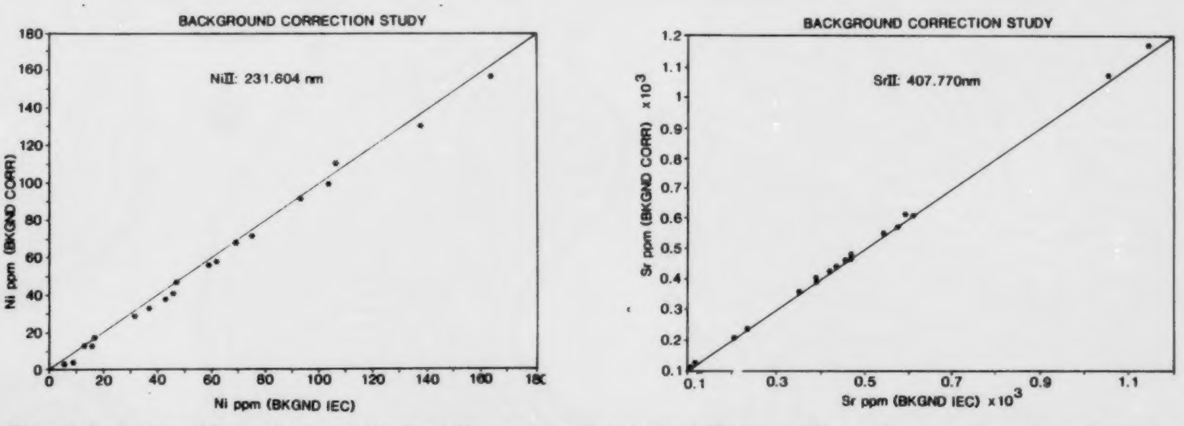

Figure 1. Comparison of the analytical results for Ni and Zn using the "offset" (labelled "BKGND CORR") and the inter-element (labelled"IEC") background correction schemes. Test samples were chosen at random from solutions prepared for routine analysis.

Table 1. Improvement in the relative standard deviation percentage (%rsd) as a result of reconfiguring the plasma and nebulizer gas lines.

Element	Gas Line Connection Effect %rsd Before (n=70)	 %rsd After (n=60)
Co	3.1	1.4
Cu	2.5	1.3
Ni	2.6	1.1
Sc	2.7	2.0
Sr	2.3	1.0
V	2.6	1.0
Zn	3.0	1.6

Table 2. Long-term measurement precision extracted from the quality control data collected between 1990 and 1991.

Element	Measurement Precision Analyst 1 %rsd	 Analyst 2 %rsd
Be	7.5	14.7
Co	2.0	3.8
Cu	1.7	2.4
Ni	2.6	5.9
Sc	1.6	3.3
Sr	2.0	3.5
V	1.9	1.9
Y	1.8	2.9
Zn	1.5	2.7

it was purchased, were suspect. We removed these fittings and force-fit the tygon gas lines over the torch and nebulizer gas ports. O-ring clamps were also used to ensure a gas-tight seal.

The instrument precision was calculated from compiled instrument quality control check solution data collected a few months before and after the change in the gas line configurations. There was a measurable improvement in the relative standard deviation percentages (%rsd) by using the force-fit connection (Table 1). It was found in subsequent experiments that it was the nebulizer connection which had the largest effect on the precision.

FORWARD POWER AND VIEWING HEIGHT

Originally the plasma was being operated at what would be considered "normal" operating conditions (1200 W power and a viewing height ca. 15 mm above the load coil). Our experience had shown that the day-to-day analytical performance was inconsistent, with some days being markedly (and unacceptably) worse than others. It appeared that the determinate error for some elements was sensitive to small changes in the operating conditions caused by daily wear-and-tear and unavoidable weekly maintenance procedures such as cleaning the torch or nebulizer.

Work on the plasma proceeded on the assumption that the inter-element effects would decrease at "hotter" plasma conditions (as was often the case in inductively coupled plasma mass spectroscopy (ICP–MS)). At the optimum conditions of 1850 W at a viewing height of ca. 25 mm, the OGS-owned instrument is being run very differently compared to the "normal" operating conditions. Comparison of the determinations of Cu and Zn by the new ICP method with both atomic absorption (AA) results (Figure 2) and reference materials (Figure 3) showed no consistent bias. All of the analytical work presented in this report used the optimized plasma conditions.

Recent work investigating the desolvation processes within the ICP (Olesik and Fister 1991; Fister and Olesik 1991) has shown that aerosol droplets can almost survive the transit through the plasma. The steep thermal gradients (100°C to 5 000°C within 1 to 2 mm) surrounding the droplets will interfere with the excitation and de-excitation processes that produce the analyte signal. This perturbation may be responsible (in part) for the determinate error associated with nonspectroscopic interferences. If this is the case,

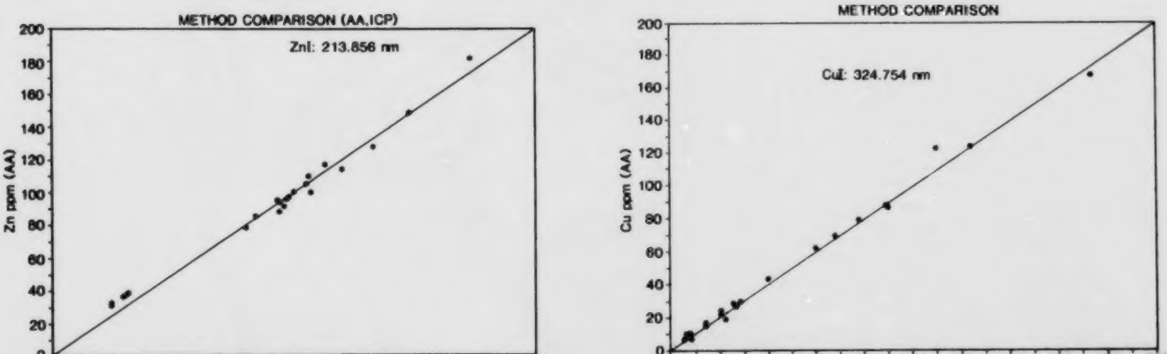

Figure 2. Comparison of analytical results for Zn and Cu on the same suite of samples using atomic absorption and ICP spectroscopy.

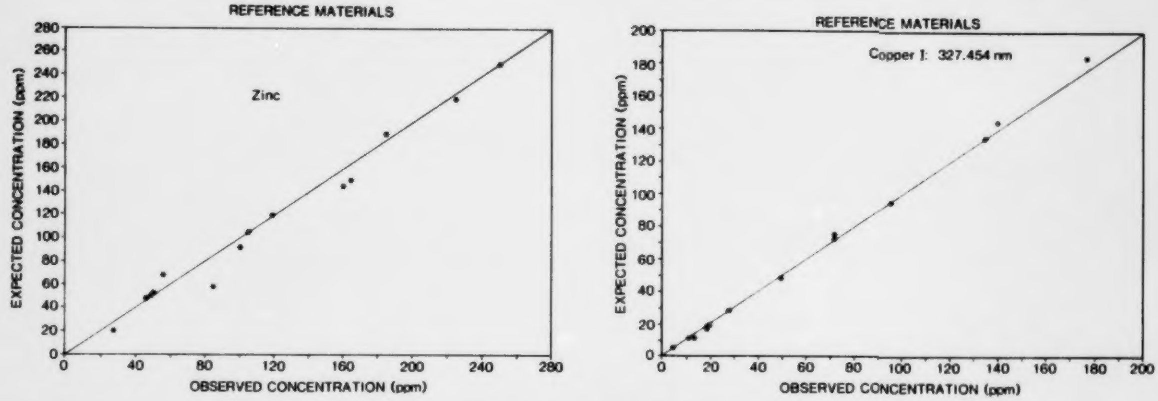

Figure 3. Comparison of the ICP Zn and Cu results with the compilation values for 13 selected geological reference materials.

then it would be preferable to run the plasma at higher powers and viewing heights where the aerosol droplet density has dropped to negligible levels. The operating conditions established at the OGS, where accuracy is the primary figure of merit, supports this line of reasoning. The laser-scattering diagnostic techniques (Olesik and Fister 1991) could prove to be an effective way of monitoring the operating conditions in the sample introduction system and in the plasma during sample analysis. Application of a laser-scattering technique to the investigation of the solid sample introduction systems for planned future OGS work (slurry nebulization and laser ablation ICP–MS) is being assessed.

RELIABILITY

Chemical data bases built up over several years need stable analytical methods to provide results which are of consistent quality. The quality control data from the instrument and digestion-control materials provides the information required to assess the methods' reliability. The instrument-check solution data collected by two analysts (Table 2) shows the plasma operating conditions to be stable, with only very small differences in the measurement precision figures. The basalt digestion control data (Table 3) shows that the overall method is rugged and reliable because the agreement of the data sets produced by two analysts was generally to within 5%. The poorer agreement for Be is an exception but this was not unexpected because of the low concentration level (0.8 ppm in rock) and the severe spectral overlap on Be by V. The quality control data implies that the documented bench procedures (OGS 1990) are sufficient to ensure continuity of service.

Table 3. Digestion-control data collected between 1989 and 1991 by two different analysts. MRB–29 is an in-house basalt reference material. Quoted precision are ±1 standard deviation. All results are in ppm.

Element	Digestion Control Data for MRB–29	
	Analyst 1	Analyst 2
Be	0.81 ± 0.04	0.98 ± 0.16
Co	44.5 ± 4.9	42.4 ± 1.5
Cu	155 ± 5	148 ± 7
Ni	99 ±1.3	102 ± 2.5
Sc	30.2 ± 0.6	29.8 ± 1.3
Sr	303 ± 6	286 ± 9
V	302 ± 6	289 ±8
Y	25.4 ± 0.4	24.2 ± 0.8
Zn	110 ± 1.4	109 ± 3

CONCLUSIONS

At the optimized instrument operating conditions established by this work, the ICP–OES based method for the determination of Co, Cu, Ni, Y, Sr, V, Be and Sc in rocks yields results which are precise (typically ±2% to ±4% rsd instrumental uncertainty), accurate (typically to within 5% to 10%) and reliable (operator independent). The general method-development procedures outlined in this report will find application to the commissioning of new ICP–OES equipment at the Mines and Minerals Research Centre facility in Sudbury.

ACKNOWLEDGMENTS

We gratefully acknowledge the recent quality control data supplied by G. Henri (ICP analyst, Geoscience Laboratories Section, OGS).

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43. Project Unit 91–16. Mineralogy and Chemistry of the Matachewan Tailings

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INTRODUCTION

On October 17, 1990, Otisse Lake about 2 km northwest of Matachewan, flooded a tailings pond adjacent to it (*see* Figure 1). This led to a major spill of tailings from the southeast part of the tailings pond into the Davidson Creek nearby, and then into the Montreal River. Based on the size of the washed-out area in the tailings pond, an estimated 200 000 tonnes of tailings flowed out of the tailings pond before the spill could be contained. The aim of this study was to provide the Response team with some idea of the mineralogical and chemical characteristics of the tailings. The purpose was to assist them in assessing the impact of the spill and to aid in possible clean-up operations. Once the basic nature of the tailings was established on four bulk samples of material from the tailings pond, interest then focused on the distribution of Pb, Zn, Cd, Hg and As in the tailings pond and on the levels of these cations in the tailings deposited in Davidson Creek and the Montreal River; at the request of the Response team other cations were also determined in samples from the Montreal River. Only a limited range of critical elements were determined in the initial samples because of the need for rapid laboratory response.

PROCEDURES

This report is based on laboratory results from the following four series of samples collected between October and December 1990, at locations shown on Figure 1 and Figure 2:

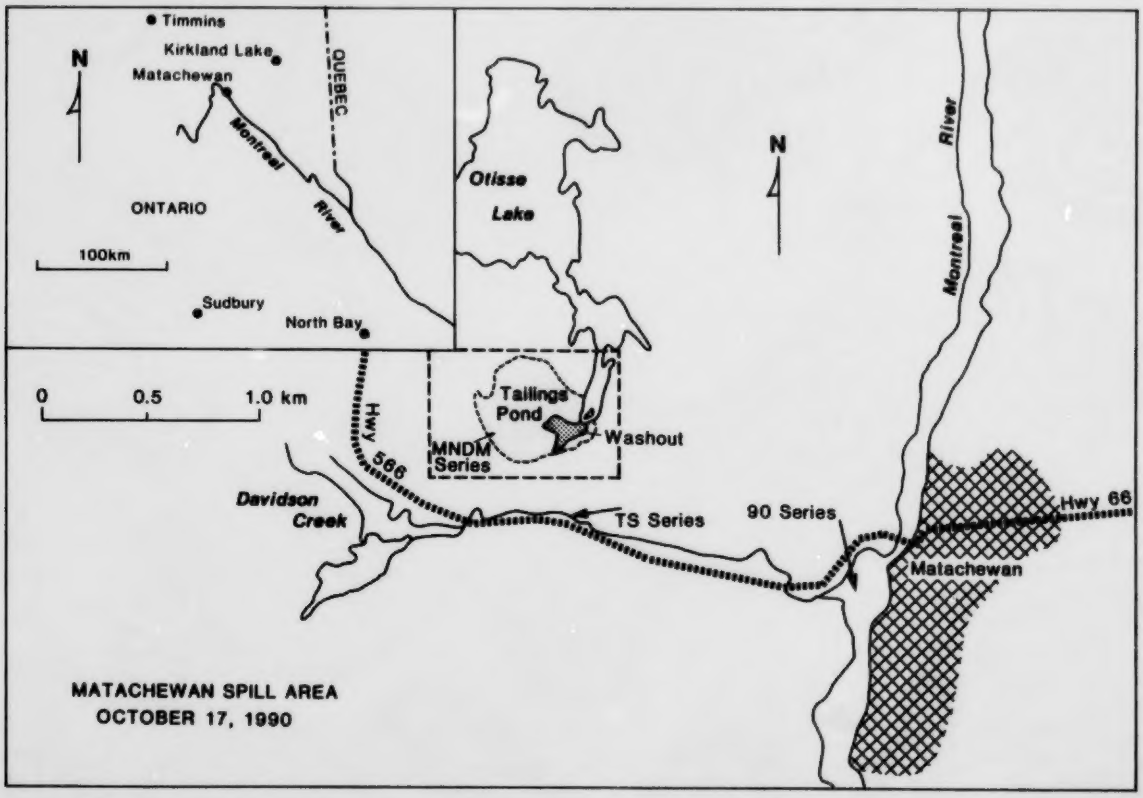
Timmins
Kirkland Lake
N
Matachewan
QUEBEC
Montreal River
ONTARIO
100km
Sudbury
North Bay
Otisse Lake
N
Montreal River
0 0.5 1.0 km
Hwy 566
Tailings Pond
Washout
MNDM Series
Davidson Creek
TS Series
90 Series
Hwy 66
Matachewan
MATACHEWAN SPILL AREA
OCTOBER 17, 1990

Figure 1. The Matachewan spill area and location of samples used in this study. The boxed area is enlarged in Figure 2.

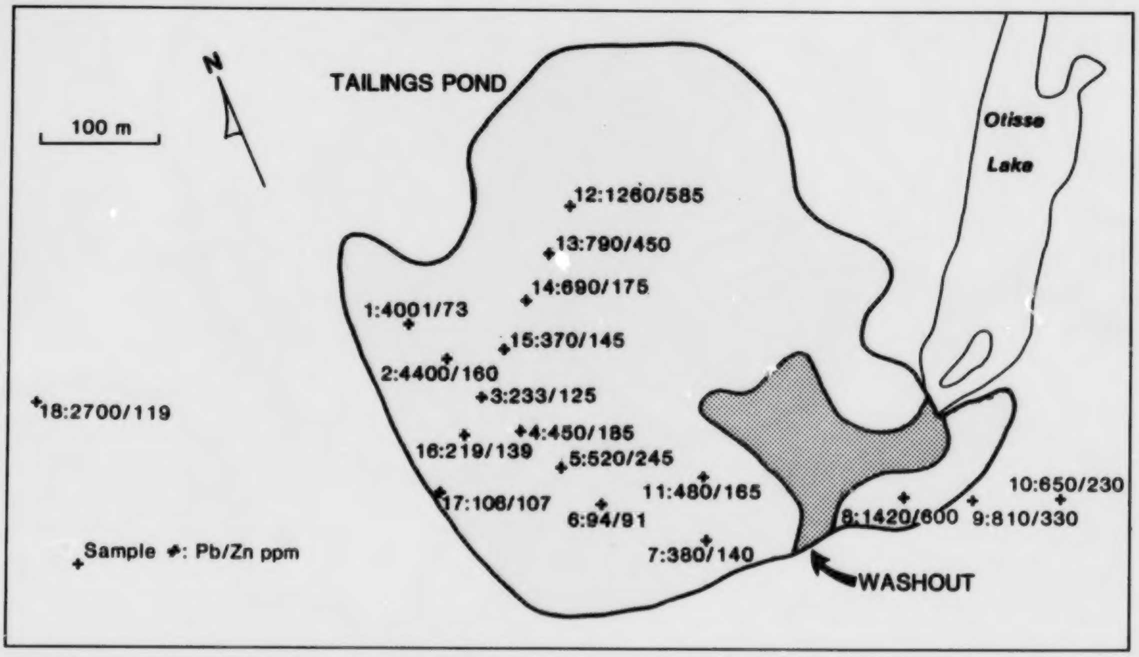

Figure 2. Location of the MNDM series samples in the Matachewan tailings pond and their Pb/Zn values.

1. DBW #1–#4 from the tailings pond
2. the MNDM series (18 samples) also from the tailings pond
3. the TS series (11 samples) from Davidson Creek
4. the 90 series of samples from the Montreal River.

Samples from the Montreal River were collected using a mini-clamshell dredge operated by the Ministry of Natural Resource. Other samples were collected with the aid of a hand-auger. Samples were stored in standard grade sample bags for shipment to the laboratory. Here they were slowly dried at 60°C in drying ovens. The coarser samples were ground to -170 mesh in alumina mills for the analytical work. The analytical procedures followed are described in the Geoscience Laboratories' manual (Ontario Geological Survey 1990). Grain size distributions by hydrometry were determined for all samples except for the MNDM series from the tailings pond.

Mineralogical characterisation of the samples was based on visual observations using a stereo microscope and on X-ray diffraction (XRD) to confirm the visual identifications. Semi-quantitative XRD data were obtained on the first series of samples from the tailings pond using the H-value method (de Souza and Rowell 1990).

Polished grain mounts of heavy mineral concentrates were prepared to identify the range of sulphides present in the MNDM series. A limited number of samples were also examined in a JEOL 840 scanning electron microscope (SEM) equipped with a PGT energy-dispersive x-ray microanalysis system (EDS), at the University of Toronto, Department of Geology. This was done in order to identify micron-sized minerals present in the tailings. Most of these are present in quantities less than 1%, which is below the detection limit of the XRD.

MINERALOGICAL CHARACTERISTICS OF THE TAILINGS

Only samples from the tailings pond and the Montreal River were examined in detail. The aim of the mineralogical study was to locate the minerals hosting elements such as Pb, Zn, Cd, Hg and As, as this had a bearing on the stability of these elements in the aquatic environment.

The tailings are composed (*see* Table 1) predominantly (c. 75%) of quartz, alkali feldspar and plagioclase in approximately equal proportions. Other silicates, such as mica (occasionally green mica), amphibole and chlorite occur in minor amounts. The carbonates, calcite and dolomite (or ankerite), comprise about 15% of the tailings. The sulphide minerals, chiefly pyrite, are less than 5%; other sulphides identified include chalcopyrite, with occasional sphalerite and galena.

SEM-EDS studies on the -60+120 mesh fraction from the MNDM series confirmed the presence of numerous micron sized inclusions such as magnetite, ilmenite, barite, zircon, monazite, pyrite, galena, sphalerite, and chalcopyrite.

Table 1. Major element chemistry and mineralogy of tailings pond samples.

	DGW1	DGW2	DGW3	DGW4
SiO_2	65.97	52.92	50.51	53.64
TiO_2	0.46	0.56	0.46	0.71
Al_2O_3	13.1	12.62	11.73	12.76
FeO	3.7	7.75	8.88	9.92
MnO	0.07	0.12	0.23	0.12
MgO	1.39	1.69	2.27	1.31
CaO	3.85	6.9	9.66	6.45
Na_2O	3.02	2.65	2.6	3.13
K_2O	4.49	4.83	3.67	4.29
P_2O_5	0.18	0.31	0.26	0.37
LOI	3.8	7.6	8.1	5.9
Total	100.03	97.95	98.37	98.6
CO_2	3.05	7.14	8.01	5.16
S	0.23	0.72	0.69	0.66
Mineralogy (Semi-quantitative XRD)				
quartz	23.5	21.5	27.4	22.7
k-feldspar	35.9	28.3	22.9	35.3
plag	26.4	24.9	19.5	27.8
biotite	0.7	1.7	1.2	0.8
amph.	2.9	0.5	3.8	
chlorite	1.1	1.7	5.4	1.3
calcite	3.7	10.7	12.7	7.8
dolomite	4.2	6.9	4.3	2.7
pyrite	1.5	3.7	2.7	1.6
chalcopyrite	tr	tr	tr	tr

Most were hosted by silicate minerals. The majority of the inclusions were completely enclosed by the host and only about 25% were partly exposed on the surface.

The mineralogy of the tailings pond samples is consistent with the description of the mineralogy of the ore bodies in the vicinity of the tailings pond (Lovell 1967). These occurred in quartz stringers either in carbonated volcanic rocks with green micas or within syenitic masses consisting chiefly of orthoclase, with minor hornblende, and secondary quartz, albite and calcite. The gold was associated mainly with pyrite, although some chalcopyrite, galena, sphalerite, tourmaline, molybdenite and scheelite have been observed.

At the request of the Response Team, the 90 series of samples from the Montreal River were split into +230 and -230 mesh fractions and each of these was further split into light and heavy fractions using methylene iodide (specific gravity of 3.2). All of these were characterised mineralogically .

Examination of the +230 mesh light fraction reveals three groups of particles:

1. fragments of (meta)sedimentary rocks including siltstones and schists (sericite, quartz, feldspar, chlorite)
2. very fine-grained volcanic rock fragments such as metabasalts and leucocratic varieties
3. monomineralic grains of quartz, pink feldspar, plagioclase, calcite and dolomite, mica (occasionally green mica) and minor amphibole.

The proportion of rock fragments in the samples decrease from about 10% in the +230 mesh fraction to almost nothing in the -230 mesh fraction. The -230 mesh light fractions are composed largely of quartz, potassium feldspar, and plagioclase, with minor mica, calcite and dolomite. The +230 and -230 mesh heavy mineral fractions contain pyrite, magnetite, hematite, garnet, tourmaline, with occasional barite, rutile, titanite, spinel, clinopyroxene, epidote, scheelite. The proportion of heavy minerals is under 0.5% for the +230 mesh fraction, increasing to under 2% for the -230 mesh fraction.

CHEMICAL CHARACTERISTICS OF THE TAILINGS

The bulk chemistry of the tailings is shown in Table 1. The quartzofelspathic composition of the tailings is reflected in the high silica and alumina values and by the high values for sodium and potassium which occur in plagioclase and potassium feldspar respectively. Significant amounts of carbonate are also present, reflecting the presence of calcite and dolomite.

Of major concern to the Response Team was the levels of Pb, Zn, Cd, Hg and As in the tailings because of hazards posed by high concentrations of these elements as discussed by Forstner and Wittman (1981). Results for these elements and others are shown in Table 2 and the rest of this section focuses on the distribution of these elements in the tailings. This discussion draws heavily on the survey of the chemical characteristics of mineral tailings in Ontario carried out by Hawley (1980). In this survey only limited numbers of samples were collected from each tailings site but it remains, to my knowledge, the only comprehensive source of information on Ontario tailings. It includes analyses of Matachewan tailings in the survey of Ontario gold camps. Local background values for the elements concerned are from the regional lake sediment and water geochemical survey carried out by the Geological Survey of Canada (Hornbrook and Friske 1988).

LEAD: The lead (Pb) values in the MNDM series samples from the tailings pond vary from 94 to 4400 ppm. SEM observations show that the Pb occurs as a few micron-sized inclusions of galena in silicates. Their distribution is not homogenous and because of this there is a "nugget effect" similar to that observed in gold assays, but accentuated by the relatively small sample weights normally used for trace element analysis. No liberated galena was identified in the mineralogical study but it is reasonable to infer the presence of "free galena" given the variability in Pb levels. Alkali feldspars may also contain up to several hundred parts per million of lead.

There is a suggestion in the distribution of Pb values from these samples (*see* Figure 2) that the tailings in the area

Table 2. Selected heavy metal concentrations and other data for the Matachewan tailings samples.

Tailings from the Montreal River

Sample#	Ag ppm	As ppm	Au ppb	Cd ppm	Co ppm	Cu ppm	Fe wt %	Hg ppb	Mn ppm	Mo ppm	Ni ppm	Pb ppm	V ppm	Zn ppm
9001-01 +230	<2	3.8	245	<2	9	74	2.57	285	700	<10	28	127	68	
9007-01 +230	<2	2.2	205	<2	6	50	1.55	13899	450	<10	25	90	52	90
9012-01 +230	<2	4.3	140	2	11	114	2.51	450	600	<10	35	163	66	147
9015-01 +230	<2	2	160	<2	<5	41	1.54	117	700	<10	24	75	57	107
9018-01 +230	<2	2.1	200	<2	<5	39	1.45	150	500	<10	23	75	56	85
mean	<2	2.88	190	2	9	64	1.92	228	590	<10	27	108	60	117
9001-01 -230	<2	12.5	510	5	26	238	4.92	820	850	<10	50	264	81	328
9007-01 -230	<2	8.2	455	5	28	292	5.28	680	1000	11	68	340	98	330
9012-01 -230	<2	9.4	450	5	29	292	5.56	720	1000	12	73	380	99	328
9015-01 -230	<2	7.7	435	4	21	204	4.24	756	850	<10	46	216	80	270
9018-01 -230	<2	8	430	5	27	268	4.88	690	950	<10	59	292	88	310
mean	<2	9.16	456	5	26	259	4.97	733	930	<10	59	298	89	313

Tailings from Davidson Creek

Sample#	Ag ppm	As ppm	Au ppb	Cd ppm	Hg ppb	Pb ppm	Zn ppm	Sb ppm	CO_2 %	pH
BULK										
TS-1S		4.3		2	nd	130	165			
TS-87S		7.2		4	68	350	285			
TS-96S		6.8		2	49	210	215			
TS-114S		6.7		2	47	260	225			
TS-3S-1		3.1		2	20	81	117			
TS-2N		2.1		2	49	42	56			
TS-51N		5.5		3	47	240	215			
TS-132N		5.5		2	38	180	200			
TS-141N		3.8		2	30	120	150			
TS-48N	<2		285	2		300	215		4.93	7.98
TS-147S	<2		325	3		500	225		5.56	7.99
mean		5	305	2	44	219	188		5.25	
CLAY Fraction										
TS-1S		6.3		3		250	130			
TS-87S		5.8		3	75	360	178			
TS-96S		8.9		3	78	375	245			
TS-114S		5.2		2	52	275	143			
TS-3S-1		4.3		3		154	99			
TS-2N		3.2		2	75	48	40			
TS-51N		4.6		2	41	245	136			
TS-132N		6.1		2	51	280	147			
TS-141N		5.8		3	39	255	143			
mean		5.5777778		3	59	249	140			
Tailings pond samples										
MNDM 1	3		1220	<2		4001	73	4	0.32	7.00
MNDM 2	<2		395	2		4400	160	1	4.14	8.26
MNDM 3	<2		760	<2		233	125	1	4.49	8.38
MNDM 4	<2		375	3		450	185	1	4.59	7.94
MNDM 5	nd	7.7	nd	3	60	520	245	nd		
MNDM 6	<2		240	<2		94	91	1	5.07	8.42
MNDM 7	<2		195	<2		380	140	1	3.27	8.35
MNDM 8	<2		420	4		1420	600	1	3.57	8.27
MNDM 9	<2		285	2		810	330	1	3.23	8.22
MNDM 10	<2		360	6		650	230	1	3.04	7.96
MNDM 11	<2		590	2		480	165	2	6.81	7.66
MNDM 12	<2		535	3		1260	585	1	4.12	8.30
MNDM 13	<2		500	5		790	450	1	4.31	8.40
MNDM 14	<2		485	3		690	175	1	3.82	8.30
MNDM 15	<2		190	3		370	145	1	3.79	8.43
MNDM 16	<2		485	<2		219	139	1	3.49	8.47
MNDM 17	<2		375	<2		106	107	1	5.71	7.90
MNDM 18	<2		2410	<2		2700	119	3	<0.01	2.53
DBW1		2.9		<2	41	71	109			
DBW2		9.4		5	88	450	350			
DBW3		33.4		5	58	960	1175			
DBW4		10.4		2	48	235	203			
mean		12.76	578	3	59	968	268	1	3.99	

in which the spill occurred have a lower Pb content than those at the western end of the tailings pond. This could explain why the Pb values in samples from Davidson Creek and the Montreal River are not as high in Pb as the tailings samples, ranging as they do from 94 to 500 ppm. Another explanation for this is that silicates with galena inclusions are more dense than other grains of the same composition, and, therefore, tend to sink out earlier. Alternatively, the tailings have mixed with sediment from other sources which have diluted the heavy metal values. This is further discussed below.

These Pb values are considerably higher than background levels in lake sediments in the area which range from 15 to 23 ppm. The data in Hawley (1980) show the Matachewan tailings to be higher in Pb than most other Ontario gold tailings, where Pb is usually less than 50 ppm.

ZINC: Zinc (Zn) values range from 73 to 1175 ppm in the tailings; there does not appear to be a pattern to the distribution of Zn values in the tailing pond. Like the Pb values, Zn is lower and not as variable in the Davidson Creek and Montreal River samples ranging from 56 to 285 ppm and 85 to 330 ppm respectively. Sphalerite (ZnS) has been identified by SEM in the tailings as well as in samples from the Montreal River. The averages from the Davidson Creek and Montreal River samples, 188 and 117 ppm respectively, are similar to local background values of 152 to 177 ppm.

Zn averages 209 ppm in Ontario tailings and exhibits a wide range of values from 10 to 4600 ppm; gold tailings, in general, are not as enriched in Zn as base metal tailings.

CADMIUM: Cadmium (Cd) values range from less than 2 to 6 ppm in the tailings samples; samples from Davidson Creek and the Montreal River display slightly lower values. In Ontario tailings, Cd ranges from 0.3 to 155 ppm, averaging less than 2 ppm in gold camps. Local background values are 1.4 to 3.5 ppm, only slightly less than those recorded in the tailings. Cadmium is usually associated with zinc in sphalerite and, as a result, tends to be high in tailings from base metal operations with high zinc concentrations. Cadmium concentrations are not usually high in gold tailings as sphalerite occurs in small amounts.

MERCURY: Mercury (Hg) values range from 41 to 88 ppb in the tailings pond, 20 to 80 ppb in Davidson Creek and 117 to 820 ppb in the Montreal River. Mercury values are generally under 1 ppm in gold mining operations and the Matachewan tailings are lower than most at less then 100 ppb. They fall within the local background values of 5 to 130 ppb.

A major source of mercury in gold tailings is the mercury sometimes used in gold processing operations. However, in this case the low Hg values suggest that either mercury was not used in processing the ores, or else it was successfully contained in the processing plant.

In this context, the higher Hg values in the Montreal River samples are puzzling. There are three possible explanations:

1. a source of Hg in the Montreal River upstream of the confluence of Davidson Creek and the Montreal River. This could be from vegetation in atrophic lakes up-stream, the Hg being released because of the flooding of the vegetation, during the period of high rainfall around the time of the spill;

2. a source in the sediments at the confluence of Davidson Creek and the Montreal River, which was released because of oxidation caused by churning of bottom sediments during the passage of the tailings plume. Examples of this elsewhere are discussed by Forstner and Wittman (1981);

3. the sample containers were contaminated.

Further sampling in the Montreal River has not confirmed these higher values of mercury.

ARSENIC: Arsenic (As) values for the tailings range from 3 to 33 ppm for the tailings compared to 2 to 7 ppm for the Davidson Creek samples and 2 to 13 ppm for the Montreal River samples. The As values measured here are an order of magnitude lower than those measured by Hawley (1980) for the Matachewan tailings which averaged 292 ppm. This was much lower than values recorded from most other gold tailings (356 to 5317 ppm) and also lower than the average for Ontario tailings of 3034 ppm. Local background values for As are 2 to 3 ppm.

The low As values recorded for the Matachewan tailings relative to other tailings imply that specific arsenic minerals are rare or absent and that much of the As may occur as trace amounts in other sulphides particularly pyrite. The association of gold with arsenian pyrites has been described by Cook and Chryssoulis (1990) and the relatively high gold values in the Montreal River samples along with the presence of pyrite, would suggest that such an association might be present here. It should be noted, however, that As was not present as a minor element in the analysis of Montreal River pyrites by SEM.

CHEMICAL VARIATIONS RELATED TO GRAIN SIZE

Grain size determinations were performed for a few tailings pond samples and for all those from Davidson Creek and the Montreal River. It was suspected that the finer fractions would be the most dispersed as well as being most enriched in heavy metals. The grain size variations in Figure 3 do show that the Montreal River samples are slightly finer than the samples from Davidson Creek, although there is substantial overlap with the latter and also with the tailings pond samples, which encompass a wider range of grain sizes. Overall, however, the data clearly indicate a degree of size fractionation as the tailings plume travelled away from the tailings pond.

Trace element analyses were performed on the -2 µm fraction in the Davidson Creek samples and on the -230 mesh

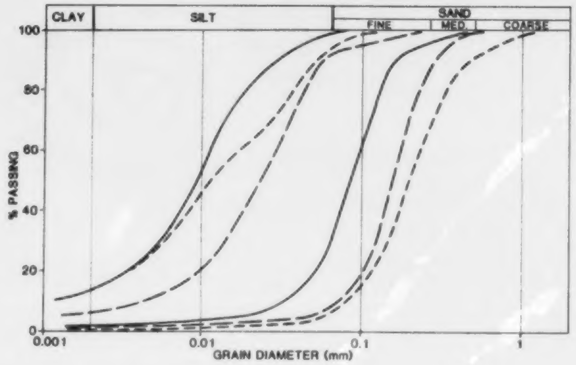

Figure 3. Grain size variations for the tailings pond samples, Davidson Creek and Montreal River samples.

(-63 µm) fraction on the Montreal River. For the latter, the two to threefold increase in metal values from the coarse- to the fine-grained fraction, is exhibited by all the heavy metal cations. The increase is not as pronounced for the -2µm Davidson Creek samples. This result is somewhat unusual in that most studies of the distribution of heavy metals with grain size show that heavy metal values are highest in the clay fraction (eg. Forstner and Wittman 1981; Biksham et al. 1991). This increase is usually thought to be a result of the finer particles with their greater surface area having a higher absorptive capacity. The source of the heavy metals is generally ascribed to anthropogenic influences.

The results from the Matachewan samples would imply that the heavy metal increases associated with absorptive capacity are masked by the contribution from mineralogical sources. This effect should be accompanied by mineralogical changes from coarse to fine fractions. The detailed examination above of the 90 series samples shows that the proportion of heavy minerals in the -230 mesh fraction exhibits a three to fourfold increase. One explanation for the increase in the metal values is that fine grinding of the rock liberates the phases containing these metals, which occur as micron-sized inclusions in silicates; these are then preferentially concentrated in the -230 mesh fraction.

DEGREE OF MIXING IN THE MONTREAL RIVER SAMPLES

As discussed above the levels of lead and zinc in the Davidson Creek and Montreal River samples are lower than those in the tailings pond. The tailings plume was highly destructive on its way to the Montreal River and therefore, it is reasonable to suspect that there has been mixing of the tailings with both surficial and fluvial sediments which would have diluted the lead and zinc levels.

The degree of mixing is difficult to assess from the mineralogy of the Montreal River samples alone. The mineralogy of the MNDM, TS and 90 series samples is similar and therefore derivation of the samples in the river from the tailings pond is likely. However, it should be pointed out that the bulk mineralogy of these samples (quartz, potassium feldspar, plagioclase with minor mica and carbonates) is not dissimilar from many tills. Nevertheless, the presence of garnet in the heavy mineral fraction of the Montreal River samples, which was not present in the tailings samples examined, suggests that mixing with tills has occurred.

There are many factors, however, which indicate that the degree of mixing is limited. Comparison of these samples with tills highlights the narrow grain-size distribution of the tailings pond, TS-series and 90-series samples. They are generally fine sands or silts, whereas glacially derived sediments tend to have a more variable grain-size distribution. The heavy mineral concentration of these samples is very low, around 1% or less compared to 5% or more in tills.

Another important difference should be in the angularity of the grains. Grains from till samples should be more rounded than the grains from tailings samples as the latter will not have been subject to the mechanical action that produces rounding in grains. Comparison of till samples with those from the 90 series shows that the grains in the former are much more rounded than those in the latter. This difference is even more apparent if the only the larger grains are examined—no rounded grains were observed in the 90 series samples.

Finally, the relatively high values recorded for gold (Au) in the Montreal River samples is strong evidence that these sediments were derived from the tailings pond. Such values would be unusual in either tills or fluvial sediments. The geochemical survey of the area shows a gold anomaly, but most of the samples were less than 10 ppb, although one was 910 ppb.

The average Au value for the bulk Montreal River sample is 402 ppb versus the 578 ppb for the tailings pond samples which would support the suggestion that a degree of mixing has occurred. Assuming that the local background is 10 ppb, a simple linear mixing model calculation suggests that the Montreal River samples could contain up to 30% of sediment from sources other than the tailings pond. Calculations using other trace elements would give different results, but it should be remembered that removal of heavy mineral phases during transportation may also be important. Nevertheless, it can be concluded, on the basis of the comparisons discussed above, that the Montreal River samples examined are composed mainly of tailings, but with a small proportion of sedimentary material derived from other sources.

NATURAL BUFFERING CAPACITY

The heavy minerals (with specific gravity > 3.2) are on average much less than 1% of the Montreal River samples, and the pyrite and other sulphides are less than half of this. The main source of acid production arises from oxidation of pyrite with the formation of sulphate anions. However, almost all of the tailings samples analyzed so far contain carbonates such as calcite and dolomite. These make up at least 10% of the sample and, therefore, will provide a significant buffering capacity in event that acid is generated from the oxidation of pyrite.

Measurements of pH carried out on the MNDM series samples (Table 2) show that pH is in the range 7 to 8.5, demonstrating the buffering capacity of the mineral assemblage. Curiously, one sample MNDM#18, was quite acidic with a pH of 2.53 and a very low carbonate content, confirming that it is indeed the carbonate that is keeping the pH high. This sample came from an isolated tailings dump not associated with the main tailings pond and not involved with the spill (*see* Figure 2).

CHEMICAL STABILITY OF THE MINERALS IN THE AQUATIC ENVIRONMENT

The stability of the minerals in the aquatic environment is very dependant on the prevailing pH and oxidation conditions. The pH of the river is 7.5 to 8 (as measured by the Response team) and it is assumed that the environment is slightly oxidizing (Eh = 0.2). Under these conditions the sulphide minerals present, such as galena and sphalerite, are virtually insoluble with solubility products of $10^{-27.5}$ and $10^{-23.6}$ respectively (Krauskopf 1967). However, according to the Eh-pH diagrams for these minerals (Garrels and Christ 1965) neither of these phases would be the stable phase under the conditions above. They are likely to oxidize to equally insoluble sulphates and carbonates.

The rates at which such changes take place can be difficult to predict because as Wieland et al. (1988) point out, reaction rates are a consequence of chemical and physical reaction steps at the mineral-water interface. And as discussed above, not all minerals hosting heavy metals necessarily have exposed surfaces. Because of this, it is not possible at present to estimate the likely levels of heavy metals in the river. Monitoring the run-off from the tailings pond for dissolved metal species may be a better guide to understanding the behaviour of the tailings in the river, although the fluvial environment is likely to be less oxidizing than the tailings pond.

CONCLUSIONS

This mineralogical and chemical study of the tailings samples from Matachewan indicates that they are largely quartzofeldspathic in nature with minor amounts of carbonate minerals and pyrite. The lead levels are significantly higher than background, but other critical heavy metals such as Zn, As, Cd, and Hg are close to background levels. The proportion of sulphides is less than 5% in the tailings and is not a concern for acid generation because of the presence of carbonate minerals to buffer any acid production. The neutral pH of the tailings pond is good evidence for this. Further studies in the area should monitor Eh-pH levels and the carbonate content of the tailings in greater detail to substantiate this conclusion.

In terms of the Geoscience Laboratories' response to the need for analytical data quickly, the requirement to dry samples prior to analysis was the limiting factor in turnaround time. This step cannot be hurried as high temperatures can affect the level of certain metals, most notably mercury. The study illustrates the capacity of the Geoscience Laboratories to provide a range of data which is the basis for a comprehensive description of the tailings. Chemical determinations allow a quick assessment of the composition of the tailings, while the mineralogical examination of the tailings is a key to predicting their behaviour.

Many of the mineralogical and chemical tests that were performed in this study are also capable of being carried out in a small mobile laboratory equipped with a field atomic absorption spectrometer and a Magstream separator for separation of heavy mineral fractions without using toxic heavy liquids. This would certainly improve response times in the event of further occurrences of this nature. As suggested by Fortescue (1990), the mobile laboratory could also be employed for baseline geochemical mapping. These maps provide vital information when assessing the impact of incidents such as the tailings spill at Matachewan.

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I am grateful to the staff of the Geoscience Laboratories for their professional response in generating the high quality data here so rapidly. I would also like to thank Rob Ferguson, Mining Development Officer in Timmins, for many enlightening discussions on the events at Matachewan.

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44. An Update Report on the Certification of the OGS In-house MRB Standard-Reference Materials

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INTRODUCTION

The Geoscience Laboratories Section has an established program for the preparation, analysis, certification and use of in-house geoanalytical standard-reference materials (SRMs). These materials are prepared in relatively small quantities (rarely exceeding 100 kg) and are generally retained only for in-house quality-assurance and methods-development programs. They are also used in the blind-standards programs (in which the Chief Analyst independently assesses the quality of analytical work on an ongoing basis) and are used in quality-assurance studies on work performed by external vendors and in joint co-operative programs. The in-house standards provide some fairly critical controls in the context of the Geoscience Laboratories Section's quality-assurance program and, as a consequence of this, this report is the first published record of their working values.

The name MRB refers to the original Minerals Research Branch (Ontario Ministry of Natural Resources), which developed an initial series of materials. Much of the original material is now used up; therefore, this report concentrates on those materials which are available in sufficient quantities. An in-house report by D. Rowell (Rowell 1990) provided a historic compilation of the characteristics of these materials and provisionally allotted values for analytes together with the associated level of confidence. Much of the analytical work on the MRB materials comes from in-house characterization, although some of the SRMs have been analyzed externally by groups who have participated in round-robin certification programs (e.g., unpublished in-house reports by Lightfoot 1988, 1989; Wilson et al. 1991). More recently, new analytical work on the standards to characterize their rare earth element abundances was initiated by C. Riddle (Chief, Geoscience Laboratories Section). This report presents a compilation of useful results based on these studies.

This report provides the most recent in-house compilation values for 25 of the 33 materials, which include standards used in lithogeochemical studies, and for studies of base and precious metals.

USE OF THE MRB-SERIES STANDARDS

The MRB reference materials are intended to serve the following 5 major functions:

1. They provide sufficient quantities of a reasonably well-characterized material so that in-house-applied methods-development work can be conducted without a shortage of reference materials. The limited availability and great cost of national and international reference standards are primarily responsible for this approach. For example, in the development of an ICP–MS method for the PGE, fire assay preconcentration procedures use as much as 25 g of material for each sample. If an international material such as SARM–7 or the Canada Centre for Mineral and Energy Technology (CANMET) standard PTC–1 was used, then the supply would be rapidly diminished. To avoid this problem, in-house standards for the platinum group elements have been developed in sufficient quantity to assist in methods development.

2. They provide sufficient quantities of a reasonably well-characterized material so that technical and scientific staffs can routinely monitor the performance of their analytical methodologies with specific regard to precision, and broad control of accuracy and determination limit problems.

3. They are to provide materials for the longer-term maintenance of quality-control information by means of the Laboratory Information Managament System (LIMS). This information may be viewed in the form of control charts and may be used by the Supervisor and Chief Analyst to assist both in the validation of data and in the evaluation of the longer-term performance of instrumental methods.

4. They are to provide the basic materials necessary for the implementation of a long-term blind-standards program so that both the precision of the methodologies can be independently evaluated by the Chief Analyst and the analytical capabilities and services can be established and presented as a guide.

5. They are to provide materials for the validation of methodologies developed at external organizations which perform analytical work for the Ministry of Northern Development and Mines. They are also to provide materials for national and international scientific-exchange programs which require a common, objective measure in order to ensure mutually compatible validation of data.

COLLECTION, PREPARATION AND CERTIFICATION OF MATERIALS

Suitable materials are identified by OGS geologists and are collected either by the geologist or by the staff of the Geoscience Laboratories Section. The more recent MRB materials have been collected in 100 kg quantities by the Geoscience Laboratories Section from representative rock types identified by OGS geologists. The basic information for MRB–7 to MRB–18, inclusive, and for MRB–29 to MRB–32, inclusive, is shown in Table 1. It includes the rock type, the mineralogy and the distinguishing features of the material. The analyst and geologist can choose appropriate standards to validate their geoanalytical data.

Rock materials are washed, dried and then crushed in a jaw crusher with chrome-steel plates. The crushed rock is then ground either in a swing-mill or in P–5 planetary mills to a -240 mesh powder. The powder is collected in 50 L pails, and then rolled within these pails to get broad homogeneity. Powders are then blended using a bench-top blender and a rotating mixer, and they are then rolled using a plastic mat to achieve complete homogeneity of the standard. If the volume of material is greater than that of the mixing vessels, then the materials are repeatedly split and mixed in order to achieve homogeneity. Once this stage has been completed, the materials are bottled, numbered and labelled. The degree of homogenization is monitored by randomly drawing a series of 10 or more bottles from the batch, then drawing 5 or more aliquots from a single bottle and then drawing 1 aliquot from each of the remaining bottles. These subsamples are analyzed by conventional methodologies and techniques (OGS 1990), and the data are reported in the form of a job to the Chief Analyst. If homogeneity has been achieved, then the precision for any single analyte will be at least as good as the within-batch precision monitored by repeated analysis of a well-characterized SRM. If this goal has not been achieved, then it may be necessary to go through the mixing process one more time. In some cases, homogeneity may never be completely achieved; for example, mica flakes will always tend to migrate to the surface of any container, and dense chromite and magnetite grains will tend to sink. For this reason, the analyst always shakes the sample vials thoroughly before extracting a subsample for analysis. In the case of a 10 L container of rock powder, this is not always straightforward, and differentiation with respect to shape and grain size can rarely be completely avoided.

Analytical data for the MRB series materials are retained from each job; traditionally, this has been a manual process, but, more recently, the introduction of LIMS technology has meant that this information can be automatically filtered out of each batch of reported data. The average, time-integrated values for the MRB materials, with clipped outlier values (beyond 6σ of the mean), are used as working values, and the associated precision is provided as a measure of certainty.

For important materials, certification is confirmed by analysis at other laboratory sites. This has been performed for all Au, Ag and platinum group element standards (MRB–20 to MRB–24).

Table 1. Characteristics of the MRB in-house standard-reference materials.

Standard	Rock type	Mineralogy	Property
MRB-7	Basalt	Fp, Am, K-Fp, Px, Chl	Dark, fine-grained with acicular Fp.
MRB-8	Rhyolite	Qz, Pl, K-Fp, Mica	Dark, fine-grained and massive
MRB-9	Felsic Volcanic	Qz, Pl, K-Fp, Px, Mica	Light-grey, medium-coarse grained.
MRB-10	Peridotite	Serp, Mt	dark, extremely fine grained.
MRB-11	Komatiite	Mt, Qz, Ank, Chl	Pale-green, medium-coarse grained, massive.
MRB-12	Altered diabase	Chl, Am, Pl, Qz	Pale-green with acicular crystals.
MRB-13	Banded iron formation	Qz, Mt/Hm	Banded texture with dark bands of Mt and light bands of Qz.
MRB-14	Andesite	Qz, Chl, Mica, Calc, Pl	Pale-green to light-grey schistose rock.
MRB-15	Rhyolite	Qz, Pl, Mica	Dark, fine-grained, hard.
MRB-16	Pegmatite	Pl, K-Fp, Qz	Light-pink, coarse-grained.
MRB-17	Pegmatite	Pl, Qz, Mica	White, Coarse-grained.
MRB-18	Li pegmatite	Spod, Qz, Pl, Mica	Pale-green bladed Spod with Qz, Pl and Mica.
MRB-29	Basalt	Pl, Px	Keweenawan mixed basalt from Osler sequence
MRB-30	Diabase	Pl, Px	Nipissing diabase
MRB-31	Granophyre	Qz, Pl, Am, K-Fp, Bi	Coarse-grained Nipissing granophyre
MRB-32	Peridotite	Serp, Chl, Mt	Altered from Kanichee mine

***Note:** Am: amphibole, Bi: biotite, Calc: calcite, Chl: chlorite, Fp: feldspar, Hm: hematite, Mt: magnetite, Pl: plagioclase, Px: pyroxene, Qz: quartz, Serp: serpentine, Spod: spodumen.*

For the more recent MRB materials (1988 onwards), a complete description of the material, its preparation and its certification is available from the Geoscience Laboratories Section.

UPDATED VALUES FOR THE MRB MATERIALS

As stated above, namely, that working values for the MRB materials are their average time-integrated values, the analytical results for the MRB standards are updated with time. This process can be carried by the LIMS since it keeps track of all the analytical data for the laboratories' standard-reference materials.

Table 2 shows the results of the most recent compilation of the major- and trace-elements values for the MRB standards. In regards to Table 2, the following explanations should be noted: 1) numbers with "*" represent values that are well determined but not certified for reference purpose; 2) Y determinations from both inductively coupled plasma mass spectrometry (ICP–MS) and X-ray fluorescence (XRF) methods are present and the results are similar, but ICP–MS gives a much lower detection limit (0.1 ppm) than XRF (5 ppm).

Table 3 shows the results for the precious-metal standards that are used specifically for quality-assurance purposes on the precious metals. The standard-deviation values for MRB–25 to MRB–28, inclusive, are also present.

SOME EXAMPLES OF THE USE OF MRB MATERIALS

MRB in-house standards are primarily used to establish new or updated analytical capabilities and to monitor the performance of these methodologies. However, the MRB materials have also been of considerable use in the monitoring of the analytical capabilities of the Geoscience Laboratories Section on both a short- and long-term basis.

Of particular interest is the recent work which has been performed with MRB–29, a Keweenawan Supergroup basalt reference material, which has been analyzed for over a year selectively with every fourth batch of samples and repeatedly within a single analytical run (Lightfoot, this volume). These results are very useful as they provide a good overall indication of the analytical precision of the Geoscience Laboratories Section. This is managed as such because these materials are introduced as unknowns with the samples, and, therefore, the analyst has no way of knowing that they are control materials.

Another example consists of the analytical results for Cu determined from MRB–7 by both inductively coupled plasma optical emission spectrometry (ICP–OES) and flame atomic-absorption (FAA) methods which are an accumulation of the analyses for more than 2 years. These results are demonstrated in 2 control charts that show the variation of analytical results through time (Figure 1). The importance of such charts rests in their use as an application in spotting deviations outside of the 2σ brackets due to long-term variations, such as instrument performance, blank effects, changes in staff and environmental system controls among others. These charts show that ICP–OES and FAA give mean and 2σ values of 81.640 and 5.715, and 81.014 and 4.737, respectively.

SUMMARY AND CONCLUSIONS

The development, characterization and use of in-house standard-reference materials are important in both methods development and the validation of geoanalytical data. The experience which the Geoscience Laboratories Section has developed with these materials will stand the organization in good stead for future ventures. Such ventures will include the selection, preparation, validation and dissemination of reference materials from the Geostandards Laboratory at the Mines and Minerals Research Centre (MMRC) facility in Sudbury.

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Table 2. Average-working major-element oxide (weight percent) and trace-element (ppm) abundances for in-house MRB standard-reference materials.

QC-TYPE	Method	MRB-7	MRB-8	MRB-9	MRB-10	MRB-11	MRB-12	MRB-13	MRB-14
SiO_2	XRFM	49.18	76.39	76.02	39.16	37.32	47.32	41.1	60.77
TiO_2	XRFM	0.91	0.16	0.14	0.11	0.31	0.34	0.05	1.10
Al_2O_3	XRFM	15.1	12.16	12.56	2.07	4.86	15.81	1.25	14.22
Fe_2O_3	XRFM	2.55	0.74	0.65	5.85	2.63	2.82	44.71	2.45
FeO	VOLUM	9.75	1.06	1.29	1.87	7.37	6.8	9.17	4.00
MnO	XRFM	0.18	0.02	0.03	0.04	0.14	0.19	0.04	0.09
MgO	XRFM	8.09	0.22	0.37	38.27	19.04	12.07	0.99	1.44
CaO	XRFM	10.57	0.58	0.85	0.08	5.41	8.80	0.98	5.02
Na_2O	XRFM	2.00	4.21	1.93	0.01	0.24	1.14	0.16	0.67
K_2O	XRFM	0.14	3.59	4.70	0.00	0.01	0.03	0.81	3.41
CO_2	INFRA	0.06	0.06	0.26	0.22	19.6	0.12	0.30	3.50
P_2O_5	XRFM	0.11	0.02	0.02	0.01	0.03	0.04	0.20	0.35
H_2O+	INFRA	1.40	0.26	0.90	11.7	2.68	4.34	0.28	2.77
H_2O-	INFRA	0.17	0.06	0.07	0.47	0.11	0.22	0.09	0.17
Total		100.20	99.53	99.79	99.86	99.75	100.04	100.13	99.96
B	INAA	5.2	6.5	35.7	51.9	0.55	9.2		40.9
As	Hydride	2.5	1.3	4.7	3.2*	4.7*	6.3	15.8	1.3*
Co	FAA	47	3	4	83*	79*	50	<5	12*
Cu	FAA	81	5	6	5	34	<5*	5	13
Ni	FAA	210	5	7	2084*	1066*	260	<5	<5
Ba	FAA	60	574	989	27*	25*	38	295*	505*
Cr	FAA	436	227	160	5080*	1735*	640	9*	9*
Li	FAA	16*	12*	16*	<3	13*	21*	9*	10*
Zn	FAA	92	22*	31*	20*	61*	68*	<5	75*
Rb	XRFT	<10	87*	89*	<10	<10	<10	105	105
Y	XRFT	14*	90*	7*	<5	<5	<5	<5	17*
Zr	XRFT	3.5	239	126	12*	20	24*	10*	256
Ga	XRFT	16	22	16	8	na	11	na	24
Be	ICP-OES	1*	2.9	1*	<1	<1*	<1*	<1*	1*
Nb	ICP-OES	4.8	24	3	<1*	8*	16*	<1*	24*
Sc	ICP-OES	23	1.6	2.1	9*	21	44	<1*	14*
Sr	ICP-OES	245	61	62	<5	30*	92*	39*	67*
V	ICP-OES	170	<5	5*	36*	126*	161*	<5	115*
La	ICP-MS	7.1	53	47	0.6	0.67	1.4	3.4	33
Ce	ICP-MS	17	120	90	1.4	1.8	3.6	7.4	73
Pr	ICP-MS	2.1	13	8	0.18	0.3	0.55	0.83	8.3
Nd	ICP-MS	9.6	51	26.5	0.9	1.7	2.8	3.5	32
Sm	ICP-MS	2.4	11	3.5	0.24	0.55	0.87	0.74	5.5
Eu	ICP-MS	0.87	0.75	0.52	0.05	0.15	0.48	0.47	1.5
Gd	ICP-MS	2.4	11	[illegible]	0.29	0.57	1.1	0.73	3.8
Tb	ICP-MS	0.42	1.9	0.2[illegible]	0.05	0.09	0.23	0.1	0.57
Dy	ICP-MS	2.9	13.5	1.4	0.4	[illegible]58	2	0.68	3.6
Ho	ICP-MS	0.58	2.9	0.25	0.08	0.12	0.58	0.16	0.7
Er	ICP-MS	1.6	8.8	0.68	0.25	0.34	1.5	0.45	1.8
Tm	ICP-MS	0.24	1.5	0.09	<0.05	<0.05	0.26	0.05	0.26
Yb	ICP-MS	1.5	9.9	0.69	0.28	0.35	2	0.43	1.8
Lu	ICP-MS	0.23	1.6	0.12	<0.05	0.5	0.29	0.07	0.27
Th	ICP-MS	<10	12*	14*	14*	<10	<10	64*	45
Ta	ICP-MS	na	na	<10	<10	na	<10	<10	<10
Y	ICP-MS	15.5	87	7.1	2.3	2.9	14	4.8	19

Table 2. (continued)

QC-TYPE	Method	MRB-15	MRB-16	MRB-17	MRB-18	MRB-29	MRB-30	MRB-31	MRB-32
SiO_2	XRFM	75.33	73.55	77.6	73.9	49.11	53.29	60.52	38.39
TiO_2	XRFM	0.47	0.13	0.01	0.02	1.96	1.19	0.77	0.42
Al_2O_3	XRFM	11.57	14.92	14.00	18.60	12.65	13.62	14.84	4.04
Fe_2O_3	XRFM	1.14	1.18	0.06	0.33	13.61**	12.85**	9.03**	17.82**
FeO	VOLUM	1.78	0.57	0.24	0.35	na	na	na	na
MnO	XRFM	0.58	0.09	0.04	0.06	0.19	0.2	0.15	0.14
MgO	XRFM	0.29	0.50	0.03	0.03	6.13	4.59	2.76	26.45
CaO	XRFM	1.20	0.89	0.20	0.11	9.53	8.08	5.35	3.01
Na_2O	XRFM	3.50	3.67	5.18	0.93	2.45	2.74	3.28	0.02
K_2O	XRFM	2.14	2.80	1.30	0.48	0.69	1.35	2.07	0.01
CO_2	INFRA	1.01	0.15	0.06	0.08	0.67	0.61	0.26	1.41
P_2O_5	XRFM	0.04	0.02	0.04	0.04	0.25	0.13	0.18	0.03
H_2O+	INFRA	0.86	0.52	0.52	0.39	4.13	0.7	1.46	6.29
H_2O-	INFRA	0.06	0.07	0.06	0.07	na	na	na	na
Total		99.97	99.06	99.34	95.39	101.37	99.35	100.67	98.03
B	INAA	13.4	2547.5	23.2	18.6	na	na	na	na
As	Hydride	0.8*	0.6*	0.6*	0.6*	na	na	na	na
Co	FAA	<5	<5	<5	<5	47	na	27	159
Cu	FAA	8	<5	<5	<5	150	na	52	3048
Ni	FAA	<5	<5	<5	<5	91	na	39	3065
Ba	FAA	440*	37*	22*	19*	289	298	371	na
Cr	FAA	86	na	153*	137*	255	na	91	2151
Li	FAA	10*	7*	50*	1.80%	na	na	na	na
Zn	FAA	87*	27*	22*	11*	117	236	61*	96
Rb	XRFT	30	110	1298	370	20.5	53	78	8
Y	XRFT	53*	8*	<5	<5	30*	27*	25*	9*
Zr	XRFT	643	20*	21*	9*	196	156	176	34.6
Ga	XRFT	26	na	32	na	na	na	na	na
Be	ICP-OES	2.6	2.8	3.3*	25*	na	na	na	na
Nb	ICP-OES	37*	6*	85*	51*	14.1	7	8	1.4
Sc	ICP-OES	10*	5	<1	1	29	na	22	10.7
Sr	ICP-OES	44*	88	25*	<10	312	214	119	41
V	XRFT	<5	<5	<5	<5	282	na	115	121
La	ICP-MS	46	3.7	0.19	0.25	20.38	na	na	na
Ce	ICP-MS	120	8.6	0.36	0.09	48.85	na	na	na
Pr	ICP-MS	15	1	<0.05	<0.05	6.3	na	na	na
Nd	ICP-MS	70	3.6	0.25	0.1	27.68	na	na	na
Sm	ICP-MS	18	0.15	0.08	0.05	6.21	na	na	na
Eu	ICP-MS	3.4	0.15	<0.05	<0.05	1.94	na	na	na
Gd	ICP-MS	14	0.89	0.09	<0.05	5.46	na	na	na
Tb	ICP-MS	1.9	0.17	<0.05	<0.05	0.83	na	na	na
Dy	ICP-MS	12	1.1	0.05	<0.05	5.1	na	na	na
Ho	ICP-MS	2.7	0.19	<0.50	<0.50	1	na	na	na
Er	ICP-MS	7.8	0.56	<0.05	<0.05	2.55	na	na	na
Tm	ICP-MS	1.4	0.09	<0.05	<0.05	0.37	na	na	na
Yb	ICP-MS	9.9	0.69	<0.05	<0.05	2.35	na	na	na
Lu	ICP-MS	1.6	0.1	<0.05	<0.05	na	na	na	na
Th	ICP-MS	<10	<10	<10	<10	na	na	12	na
Ta	ICP-MS	<10	<10	<10	21	0.84	na	na	0.08
Y	ICP-MS	65	6.9	0.4	0.1	25.08	na	na	na

Note: **: values that are less well determined. **: total Fe presented as Fe_2O_3*
XRFM: X-Ray Flurescence Analysis for Major Elements
XRFT: X-Ray Flurescence Analysis for Trace Elements
INAA: Instrumental Neutron Activation Analysis; Hydride: Hybrid Generation-Atomic Absorption, FAA: Flame Atomic Absorption.
Preliminary values for MRB–29 to 32 inclusive were based on initial characterisation following preparation. na: not available.
Major element oxides, CO_2, H_2O+ and H_2O- are given in wt.%, and trace element abundances are given in ppm.

Table 3. Working values for the MRB precious metal in-house standard-reference materials.

Standard	Au(ppb)	Pd(ppm)	Pt(ppm)	Rh(ppb)	Ru(ppb)	Ir(ppb)	Os(ppb)
MRB–19	450	1.784	0.728	228	65	37	10
MRB–20	269	1.154	1.395	149	108	48	24
MRB–21	5616	243.929	69.872	2362	730	287	271
MRB–22	1344	71.219	23.551	876	255	84	101
MRB–23	2810	90.126	31.643	915	339	126	145

	Au (oz/ton)		Ag (oz/ton)	
	Mean	Std dev	Mean	Std dev
MRB–25	1.69	0.06	2.46	0.17
MRB–26	0.38	0.02	10.86	0.65
MRB–27	na	na	45.09	0.57
MRB–28	1.24	0.11	98.00	1.32

Note: *MRB19 & 20 are massive sulfides from Frood Mine, 1000 level, 2296 Drift, Sudbury Igneous Complex.*
MRB21, 22 & 23 were from ore stock pile, Minneapolis Adit, Stillwater Intrusion.
MRB25–28 included represents samples 275, 142, 125 and 215 donated by Prof. Hewer (Lightfoot, 1989).

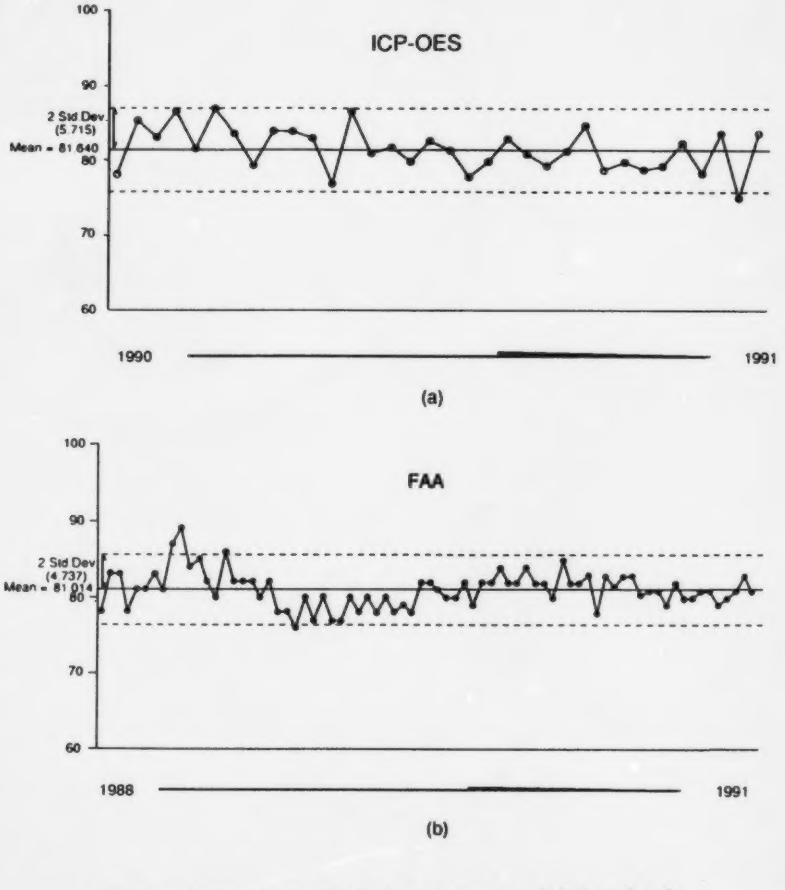

Figure 1. Control charts showing the variation of analytical results of MRB–7 on Cu by a) ICP–OES and b) FAA methods through time. The vertical axis is graduated in ppm. Note that the horizontal scale of time used in (a) is not equivalent to that used in (b).

45. Mineral Potential of the Nipissing Diabase: some Geochemical Considerations

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INTRODUCTION

The Nipissing diabase magmatic province was formed by the emplacement of large volumes of tholeiitic magma into the Early Proterozoic Huronian supracrustal belt within central Ontario, Canada. This produced a series of undifferentiated to differentiated diabase intrusions stretching from Sault Ste. Marie, in the west, to Cobalt, in the east (Figure 1). Much of the magmatism is associated with the Huronian volcano-sedimentary basin and the fault zones to the north of the Grenville Front.

The style of mineralization associated with Nipissing sills changes across the province (Card and Pattison 1973). Near Sault Ste. Marie and Bruce Mines, quartz vein copper mineralization predominates. Near Sudbury the dominant style is gold, copper, nickel and platinum group element (PGE) mineralization. At Cobalt and Gowganda, quartz carbonate vein silver mineralization occurs associated with the Nipissing intrusions.

The Nipissing diabase has recently been the subject of petrographic, geochronological, and geochemical studies (e.g. Lightfoot and Naldrett 1989, in prep.; Noble and Lightfoot, in prep.; Conrod 1988) which have yielded three important findings:

1. The chilled margins and undifferentiated diabases from intrusions located in some areas of the Nipissing province appear to be quite uniform in composition.
2. *In situ* differentiation of the magma was, at least in part, coupled to the assimilation of anatectic melts of the overlying Huronian sediments.
3. The emplacement of at least three Nipissing intrusions occurred over a relatively short time span of some 10 million years (Noble and Lightfoot, in prep.).

In this paper, we extend these studies by presenting an interpretation of new, precise and accurate major- and trace-element data from the Kukagami Lake sill which is located near Sudbury. Importantly, the Kukagami sill (which is presumably an extension of the Wanapetei Intrusion which hosts the Rathbun Lake occurrence) contains a small, yet significant, showing of apparently magmatic nickel-copper-sul-

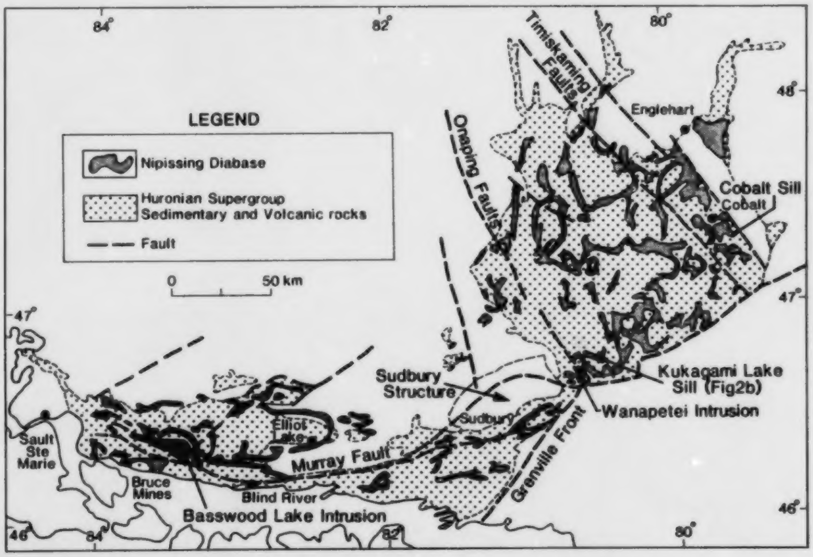

84°
82°
80°
48°
47°
46°
LEGEND
Nipissing Diabase
Huronian Supergroup Sedimentary and Volcanic rocks
Fault
0
50 km
Timiskaming Faults
Englehart
Onaping Faults
Cobalt Sill
Cobalt
Kukagami Lake Sill (Fig2b)
Wanapetei Intrusion
Sudbury Structure
Sudbury
Grenville Front
Sault Ste Marie
Elliot Lake
Murray Fault
Bruce Mines
Blind River
Basswood Lake Intrusion

Figure 1. Map showing the distribution of Nipissing diabase, Huronian sediments and basement, and the major fault lines in Central Ontario. The location of the Kukagami Lake sill and other study areas are shown.

fide enriched in the platinum group elements and gold. Other intrusions further west and east have been studied (Lightfoot et al., in prep.), but do not develop nickel-copper-PGE-gold-enriched sulfide mineralization.

It is important to ascertain how differentiated and contaminated the parental magma to the Kukagami Lake sill was, because the extent of differentiation or contamination might control the stage at which magmatic sulfides may segregate and deplete the magma in Ni, Cu, and the platinum group elements (Irvine 1975). In this study we investigate the composition of the parental Nipissing magma and look for distinctive petrological and geochemical signatures associated with the barren and mineralized intrusions. We show that mineralized intrusions may be identified on the basis of their major and trace element chemistry.

BACKGROUND GEOLOGY

The 2.2 Ga (Corfu and Andrews 1986; Noble and Lightfoot, in prep.) Nipissing Diabase magmatic Province lies in central Ontario and outcrops dominantly within the Proterozoic Huronian supracrustal belt (see Figure 1) with an east-west extent of almost 450 km, and a north-south extent of up to 350 km. Almost 25% of this area is covered by Nipissing diabase at, or near to, the surface, and the sills generally extend at depth within the Huronian supracrustal package. Though much eroded, the total volume of diabase is well in excess of 100 000 km^3. Although not comparable in scale to intrusive activity associated with many of the Mesozoic and Recent continental flood basalts (CFB) [e.g the Karoo dolerite province of Southern Africa (Marsh and Eales 1984); the intrusive Traps of Siberia (Lightfoot et al. 1990); and the Tasmanian dolerites (Hergt et al. 1989)], it is still a very significant relic of a Proterozoic equivalent of these CFB. Over 90% of the exposed Nipissing sills and dikes penetrate the Huronian sedimentary basin or the Murray fault zone; thin irregular dikes and sills are known to cut the Precambrian basement in a few locations to the north of the Huronian basin.

Most of the Nipissing intrusions show very little differentiation, and consist of a distinctive, and highly uniform, quartz diabase; in contrast, some of the intrusions are highly differentiated, generally ranging in composition upwards through the intrusions from quartz diabase, to hypersthene diabase through varied-texture diabase, into granophyric diabase and aplites (e.g. Conrod 1988; Jambor 1971; Bowen 1910; Hriskevich 1952, 1968; Card and Pattison 1973; Lightfoot and Naldrett 1989). The dominant rock types are quartz diabases and gabbros, and the petrography of the freshest undifferentiated rocks is relatively simple with phenocrysts limited to orthopyroxene and plagioclase (and very minor olivine in a few intrusions and resorbed augites in some intrusions) enclosed ophitically in clinopyroxene and pigeonite, with minor accessory olivine, ilmenite, quartz, potassium feldspar, and opaque mineral phases.

Relatively undifferentiated intrusions are common in the centre of the Province between Sudbury and Temagami, and some of the intrusions closer to Sudbury host sulfides which may be of magmatic or hydrothermal origin (e.g. the Kukagami and Rathbun Lake showings - Rowell and Edgar 1986; Rowell 1984). Between Bruce Mines and Elliot Lake, in the west, and between Cobalt and Gowganda, in the northeast, the intrusions are frequently more strongly differentiated and are apparently almost barren of magmatic sulfide mineralization.

GEOLOGY OF SELECTED INTRUSIONS

In this study, we have analyzed samples across the magmatic province, from the western area (the Basswood Lake intrusion), the central area (the Kukagami Lake Sill and the Wanapetei Intrusion), and from the northeastern area (the Cross Lake Sill) (*see* Figure 1) to determine if there was any regional variation in the composition of the parental magma and whether the amount of *in situ* differentiation nature and properties of cumulus mineral phases vary across the magmatic province. In this report, we concentrate attention on the Kukagami Lake sill; results for the other intrusions will be presented elsewhere (Lightfoot et al., in prep). The Kukagami Lake Sill (*see* Figure 2) is exposed in Kelly Township, northeast of Sudbury. It falls along strike and may be part of the Wanapetei intrusion, which hosts a small, high-grade sulfide body rich in copper, platinum, and palladium (e.g. Dressler 1982; Rowell 1984; Rowell and Edgar 1986), called the *Rathbun Lake occurrence*. The Kukagami Lake sill is entirely hosted within Huronian Supergroup Lorrain Formation greywackes. Quartz diabase outcrops along the northern margin of the sill, and grades upwards into a thick (>50 m) hypersthene diabase unit (≤ 20% modal hypersthene) towards the south. Disseminated, net-textured, and blebby sulfide mineralization occurs in the hypersthene-rich diabase at greater than 50 m above the base of the intrusion. The sulfides consist dominantly of pyrite, chalcopyrite, and some pyrrhotite, and outcrop in two locations (*see* Figure 2) over a surface area of about 1000 m^2, and constitute up to 5% of the rock. The sulfides occur disseminated throughout the hypersthene diabase between crystals of hypersthene, and in more massive patches. The patches are devoid of features such as sulfide ovoids which might suggest *in situ* differentiation. This contrasts with the *in situ* differentiation features shown by sulfide blebs from the hypersthene diabase above the Rathbun Lake showing in the Wanapetei Intrusion. These blebs have differentiated into Cu-rich chalcopyritic upper portions and pyrrhotite-rich lower portions (Lightfoot 1987). This feature has been recorded in magmatic sulfides from the Insizwa Complex of the Karoo, Southern Africa (Scholtz 1936; Figure 5 from Lightfoot et al. 1984), and the Talnakh Intrusion of the Noril'sk Region, USSR (unpublished data). Whereas we have not unambiguously shown that the Kukagami and Wanapetei intrusions are contiguous, Figure 2 shows that

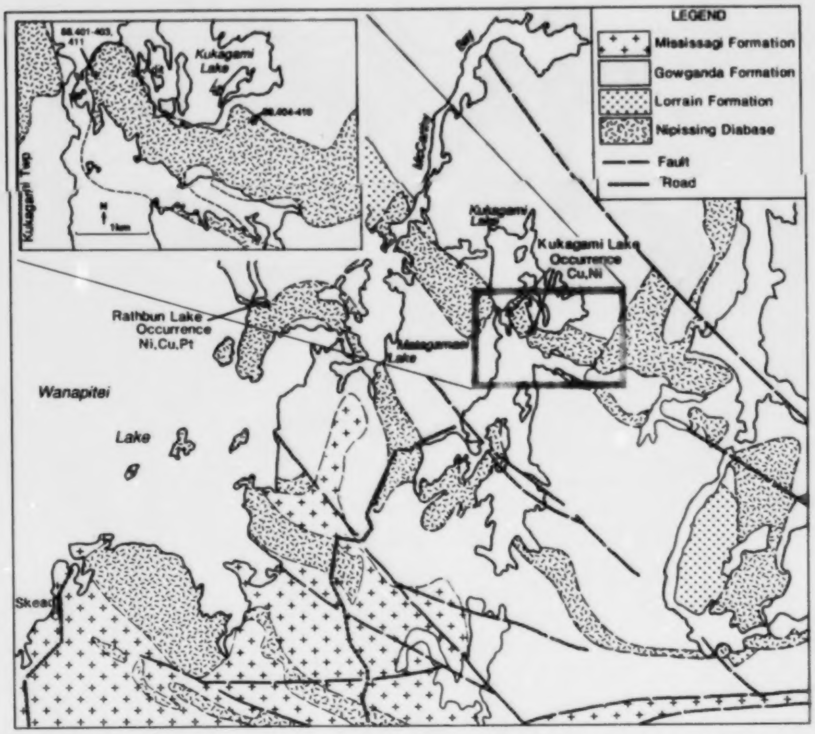


Figure 2. Detailed geology of the Kukagami Lake study area and sample locations, and the setting in relation to the Wanapetei intrusion.

both may fall along strike within the same broad sill complex. This would appear to suggest that this sill complex may make an excellent target for further mineral potential evaluation.

ANALYTICAL METHODS AND RESULTS

Samples were collected from the three sills at the locations shown in Figure 2. All weathered surfaces were removed in the field. Samples greater than 3 kg were jaw-crushed with steel plates, and powdered using 99.8% pure alumina planetary mills. Major elements, Rb, Sr, Zr, and Nb were analyzed by wavelength dispersive X-ray fluorescence and additional trace elements were analyzed by atomic absorption spectroscopy (Cr, Ni, Co, Cu, Zn, Ba), inductively coupled plasma emission spectroscopy (Sc, V), and inductively coupled plasma mass spectrometry (the REE, Y, Th, U, Ta, and Hf) in the Geoscience Laboratories, Ontario Geological Survey (details of methods and procedures are given in: Geoscience Laboratories 1990; Doherty et al. 1990). Precision and accuracy are documented relative to standards UTB-1 and BHVO-1 (*see* Table 1); analyses are given in Table 1. Determinations of S are by a Leco infrared technique; Pt, Pd, and Au are by lead fire assay and graphite furnace atomic absorbtion spectroscopy; the remaining PGE by nickel sulfide fire assay and neutron activation analysis (e.g. Geoscience Laboratories 1990; *see also* Table 2).

COMPARATIVE MAJOR AND TRACE ELEMENT GEOCHEMISTRY OF NIPISSING INTRUSIONS

The undifferentiated Nipissing diabase is quartz normative lithology with moderate SiO_2 and low Fe_2O_3. Samples from the Basswood Lake Intrusion (*see* Figure 1) have the widest compositional range (Lightfoot et al., in prep.), probably reflecting the strong *in situ* differentiation and contamination process that has been identified in other Nipissing diabase sills such as the Kerns sill (e.g. Lightfoot and Naldrett 1989). This range is reflected in the strong iron-enrichment trend from gabbros through to granophyres. Between the quartz diorites and compositionally extreme granophyres, there is an inflection in the trend towards more alkalic compositions. This trend resembles that found in many other compositionally layered mafic sills and intrusions such as the Pallisades and Skaergaard intrusions (Wager and Deer 1939; Walker 1969a, 1969b), and reflects the typically tholeiitic to slightly calc-alkaline differentiation trend of these magmas. The samples of quartz diabase and hypersthene diabase from the Cobalt sill (*see* Figure 1)) are compositionally similar (Lightfoot et al., in prep.) to the Basswood Lake intrusion lithologies; coarser varied-textured diabases also fall on the iron-enrichment trend. Samples from the mineralized Kukagami sill quartz and hypersthene diabases are relatively alkali poor compared to equivalent lithologies in the other

Table 1. Whole rock major element oxide and trace element compositional data for Nipissing diabase samples from Basswood Lake, Kukagami Lake, and the Cobalt Intrusions.

Location	Sample No.	Mg-number	SiO_2 (wt.%)	TiO_2 (wt.%)	Al_2O_3 (wt.%)	Fe_2O_3 (wt.%)	MgO (wt.%)	MnO (wt.%)	CaO (wt.%)	Na_2O (wt.%)	K_2O (wt.%)	P_2O_5 (wt.%)	L.O.I. (wt.%)
KLS	88-401	0.619	51.4	0.46	11.68	15.22	10.63	0.23	9.20	0.81	0.34	0.03	2.80
KLS	88-402A	0.622	51.6	0.43	15.81	11.29	7.99	0.21	10.88	1.33	0.40	0.03	2.40
KLS	88-402B	0.658	50.3	0.39	14.04	11.11	9.19	0.15	13.03	1.46	0.30	0.03	0.50
KLS	88-403A	0.654	50.6	0.43	13.61	11.17	9.07	0.16	12.90	1.61	0.42	0.04	1.20
KLS	88-403B	0.563	49.8	0.43	14.15	14.46	7.99	0.17	10.95	1.48	0.57	0.04	2.90
KLS	88-404	0.605	49.4	0.45	13.42	13.73	9.03	0.17	11.98	1.36	0.45	0.04	1.30
KLS	88-405	0.691	52.0	0.43	14.78	9.46	9.10	0.15	12.33	1.24	0.50	0.04	1.70
KLS	88-406	0.681	51.9	0.49	14.39	9.81	8.99	0.16	12.18	1.60	0.40	0.05	0.50
KLS	88-407A	0.604	49.4	0.39	14.11	13.28	8.71	0.17	12.14	1.32	0.46	0.04	1.70
KLS	88-407B	0.575	48.6	0.41	14.07	14.49	8.42	0.17	11.99	1.44	0.42	0.02	2.00
KLS	88-410	0.662	50.6	0.41	14.43	11.03	9.29	0.16	12.68	0.92	0.41	0.04	2.10
KLS	88-411A	0.659	51.3	0.34	10.05	15.31	12.70	0.28	9.11	0.52	0.32	0.02	3.00
KLS	88-411B	0.651	51.4	0.42	9.59	15.72	12.62	0.30	9.26	0.46	0.20	0.05	2.90
Standard MRB-29			49.5	1.91	12.56	13.46	6.09	0.18	9.25	2.39	0.71	0.25	2.08
2σ			0.3	0.04	0.11	0.11	0.06	0.01	0.06	0.14	0.02	0.02	

FOOTNOTES:
KLS = Kukagami Lake Sill
LOI = Loss on ignition
All major element oxide abundances are calculated to 100% free of LOI.
A and B designation of sample number refer to duplicate field samples from outcrop.

Location	Sample No.	Ba (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Ta (ppm)	Hf (ppm)	Th (ppm)	U (ppm)	Cu (ppm)	Ni (ppm)	Cr (ppm)	Zn (ppm)	Co (ppm)
KLS	88-401	68	19	99	14	57	n.d.	0.10	0.80	1.50	0.50	1480	545	117	155	89
KLS	88-402A	58	22	153	11	51	n.d.	0.10	0.80	1.10	0.40	93	105	83	83	46
KLS	88-402B	72	15	103	13	48	n.d.	0.10	0.90	0.90	0.30	3200	1650	905	62	78
KLS	88-403A	92	19	115	12	50	n.d.	0.10	0.80	1.00	0.30	3150	1790	825	89	78
KLS	88-403B	97	29	144	13	60	n.d.	0.10	1.10	1.40	0.50	2530	860	165	122	99
KLS	88-404	86	21	128	12	52	n.d.	0.10	1.00	1.10	0.40	9000	3550	615	97	121
KLS	88-405	62	20	158	12	57	n.d.	0.10	0.90	1.10	0.40	655	375	625	65	40
KLS	88-406	92	21	135	15	59	n.d.	0.10	1.10	1.20	0.40	90	130	580	75	40
KLS	88-407A	85	21	122	13	47	n.d.	0.10	0.90	0.90	0.30	8000	2800	695	79	100
KLS	88-407B	78	20	118	12	46	n.d.	0.10	0.90	0.90	0.30	11000	3900	550	82	135
KLS	88-410	64	17	144	12	50	n.d.	0.10	0.90	0.80	0.20	3725	2040	750	82	88
KLS	88-411A	69	21	58	10	37	n.d.	0.00	0.60	0.70	0.20	525	295	192	138	69
KLS	88-411B	52	14	60	11	47	n.d.	0.10	0.90	1.00	0.30	805	395	145	117	79
Standard MRB-29		314	13.91	303	24.9	174	13.9	0.83	4.7	2.32	0.54	151	99	265	107	47
2σ		.16	0.36	6	0.3	5	0.3	0.04	0.3	0.13	0.04	10	3	7	12	1

n.a. = not analyzed
n.d. = not detected

Location	Sample No.	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)
KLS	88-401	5.00	11.30	1.50	6.30	1.64	0.50	1.95	0.32	2.40	0.51	1.63	0.22	1.46	0.22
KLS	88-402A	4.30	9.46	1.30	5.00	1.35	0.52	1.60	0.28	1.94	0.42	1.30	0.17	1.21	0.18
KLS	88-402B	4.30	9.70	1.30	5.30	1.61	0.51	1.80	0.31	2.18	0.47	1.41	0.19	1.28	0.20
KLS	88-403A	4.30	10.00	1.30	5.60	1.45	0.54	1.79	0.31	2.20	0.46	1.34	0.20	1.28	0.20
KLS	88-403B	5.50	12.60	1.60	6.30	1.45	0.54	1.79	0.31	2.12	0.46	1.34	0.20	1.28	0.20
KLS	88-404	4.30	9.90	1.30	5.30	1.49	0.51	1.77	0.30	2.07	0.44	1.32	0.19	1.23	0.20
KLS	88-405	4.90	10.40	1.40	5.60	1.51	0.48	1.77	0.30	2.07	0.45	1.41	0.19	1.25	0.19
KLS	88-406	5.40	11.80	1.60	6.80	1.95	0.64	2.08	0.38	2.72	0.56	1.69	0.25	1.52	0.24
KLS	88-407A	4.40	9.50	1.30	5.60	1.58	0.51	1.82	0.33	2.26	0.48	1.47	0.19	1.37	0.21
KLS	88-407B	4.20	9.30	1.20	5.40	1.54	0.55	1.93	0.33	2.29	0.46	1.44	0.20	1.34	0.21
KLS	88-410	4.40	9.10	1.20	5.50	1.59	0.53	1.89	0.33	2.29	0.48	1.45	0.20	1.37	0.21
KLS	88-411A	3.20	6.70	0.90	3.80	1.16	0.35	1.34	0.24	1.79	0.38	1.16	0.16	1.18	0.18
KLS	88-411B	4.00	8.70	1.10	4.70	1.28	0.37	1.64	0.28	2.07	0.45	1.31	0.19	1.40	0.23
Standard	MRB-29	20.52	49.55	6.09	26.48	6.18	1.88	5.72	0.82	5.21	0.99	2.52	0.37	2.34	0.35
2σ		0.64	1.10	0.31	0.40	0.10	0.07	0.31	0.02	0.20	0.05	0.13	0.03	0.08	0.01

Table 2. Base and precious metal abundances in mineralized samples from the Kukagami Lake sill and Rathbun Lake showing of the Wanapetei intrusion.

Table 2a. Au, Pt, Pd, and S data for the Kukagami lake sill.

Sample	No.S (wt.%)	Au (ppb)	Pt (ppb)	Pd (ppb)	Comments
88-404	2.18	230	670	3225	
88-404		280	670	3350	Duplicate
88-405	0.23	24	65	340	
88-405		60	67	320	Duplicate
88-401	0.93	45	9	14	
88-402A	0.14	3	2	1	
88-402B	1.00	90	215	1840	
88-403A	1.11	80	210	1730	
88-403B	1.81	90	21	48	
88-406	0.08	2	17	62	
88-407A	2.11	600	945	4160	
88-407B	2.96	430	1100	4000	
88-410	1.20	90	210	1450	
88-411A	0.30	16	n.d.	32	
88-411B	0.61	21	7	23	

FOOTNOTES:
Duplicate analysis were performed on rock pulps.
Sample suffix A and B correspond to sub-splits of large (>5kg) samples collected in field.
Ni, Cu, and Co are given in Table 1.

Table 2b. Ni, Cu, Co, S, and PGE data for sulfides from the Rathbun Lake showing.

Sample	S (wt.%)	Cu (ppm)	Ni (ppm)	Co (ppm)	Au (ppb)	Pd (ppb)	Pt (ppb)	Rh (ppb)	Ru (ppb)	Ir (ppb)	Os (ppb)
Massive chalocopyrite-rich sulfide in greywacke, Wanapetei Intrusion											
87-09	17.8	124000	8705	326	1050	24000	3275	n.d.	11	.05	10
87-11	18.3	115000	11200	404	3170	53000	6325	n.d.	n.d.	n.d.	n.d.
87-15	16.0	139000	9500	150	6410	17700	2550	n.d.	n.a.	n.a.	n.a.
Disseminated chalcopyrite-rich sulfide from basal quartz diabase, Wanapetei Intrusion											
87-04	2.9	17800	7360	272	n.a.	23090	929	n.d.	n.d.	0.05	n.d.
87-05	6.8	32000	6640	336	1630	6650	1750	47	n.d.	0.191	
87-07	13.1	42000	3240	310	4440	34500	3050	37	n.a.	n.a.	n.a.
87-08	3.5	29600	3760	188	565	34500	1155	n.d.	n.d.	0.10	7
87-10	2.4	17700	1960	38	1260	11100	58	n.d.	n.d.	0.09	n.d
Disseminated sulfide in quartz diabase, Wanapetei Intrusion											
87-01	1.3	3150	1320	116	275	4350	420	7	2.7	0.34	2
87-02	1.5	2650	1280	138	1010	8700	1045	5	n.d.	0.11	4
87-03	0.4	1860	950	60	95	2110	215	n.d.	n.d.	0.21	n.d.
87-06	1.1	5500	1610	60	125	1250	308	n.d.	n.d.	0.111	
87-12	0.6	3260	396	46	200	1025	149	n.d.	2	n.d.	1
87-25	1.4	3350	1430	86	265	200	130	2	16	n.d.	n.d.
Disseminated sulfide from roof-zone granodiorite, Obabika sill, Lake Temagami (Lightfoot and Naldrett, unpublished data)											
87-402	0.04	40	<5	14	192	339	221	1	n.d.	0.49	1
87-404	0.05	93	76	32	15	31	14	n.d.	6.6	0.77	1
Disseminated sulfide from roof-zone aplite, Kerns sill, Temiskaming (Lightfoot and Naldrett, 1988)											
87-411	1.2	9	16	12	35	n.d.	11	n.d.	2.2	0.06	1

FOOTNOTES:
n.a. not available; n.d. not detected.

intrusions, but have slightly higher FeO/MgO (*see* Figure 3). The position of the field of the diabase from the Kukagami sill relative to diabases from the other intrusions is presumably an artifact of the contribution of Fe from sulfides in these mineralized samples (<5% combined chalcopyrite and pyrrhotite). Figure 3 shows the sulfide control line back-projected to intersect the trend of the data from the other sills, which suggests that on AFM grounds alone, these rocks are only different from unmineralized diabases in-so-far as they contain sulfides.

All of the diabase and varied-textured diabase samples from the Nipissing intrusions fall in the sub-alkaline field on the diagram of Na_2O+K_2O versus SiO_2 (Miyashiro 1978). Many of the coarse-grained granophyres from the Basswood Lake Intrusion fall close to the boundary between alkalic and sub-alkalic rocks, but the finer-grained granophyres are displaced above the boundary and are well within the field of alkalic rocks.

Major element variation diagrams reflect many features identified by Lightfoot and Naldrett (1989), but the variations in the Kukagami Lake sill are subtly different. Variation in TiO_2 and Zr versus Mg-number (Figures 4a and 4b) indicate that the Kukagami Lake quartz and hypersthene diabases have slightly lower Mg-numbers (as low as 0.55) than samples from the Basswood Lake Intrusion (as low as 0.6), at comparable Zr levels (40 to 60 ppm). There is also a wide spread in Cr (80 to 900 ppm), Ni (92 to 3900 ppm), Co (38 to 135 ppm), and Cu (90 to 11 000 ppm) in the sulfide-bearing Kukagami Lake diabases. These variations clearly reflect the variable modal content of pyrrhotite and chalcopyrite. However, there is also a wide range in Sr (58 to 158 ppm) in the Kukagami Lake diabases, with abundances generally lower than typical quartz and hypersthene diabases (usually 130 ppm, or more). Although Sr may be mobile under greenschist facies conditions, the data for the diabases define a broad increase in Sr with Zr (*see* Figure 4c), which suggests that even if Sr is mobile, the rocks retain at least a broad hint of the original geochemical signature of the more mobile analytes. The depletion of Sr in the Kukagami Lake samples is accompanied by very depressed Al_2O_3 (*see* Figure 4d; 9.5 to 15.7 wt.%) compared to the less differentiated diabases of the Basswood Lake intrusion (14 to 18.5 wt.%). This is accompanied by a small yet significant depletion of some of the Kukagami Lake samples (i.e., those with MgO=10.25 to 12.5 wt.%), compared to compositions which would fall on an extension of the array of Basswood Lake diabases (*see* Figure 4e).

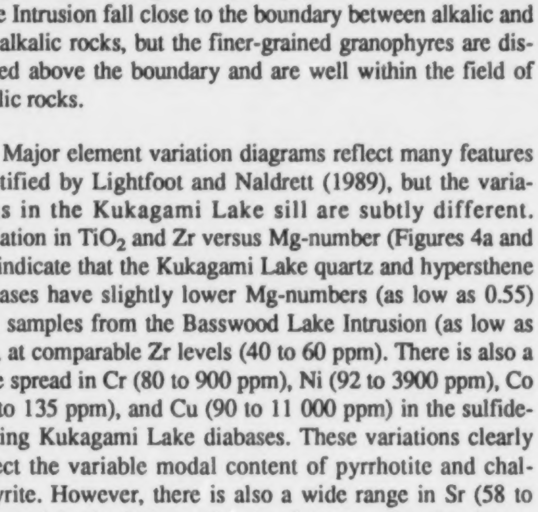


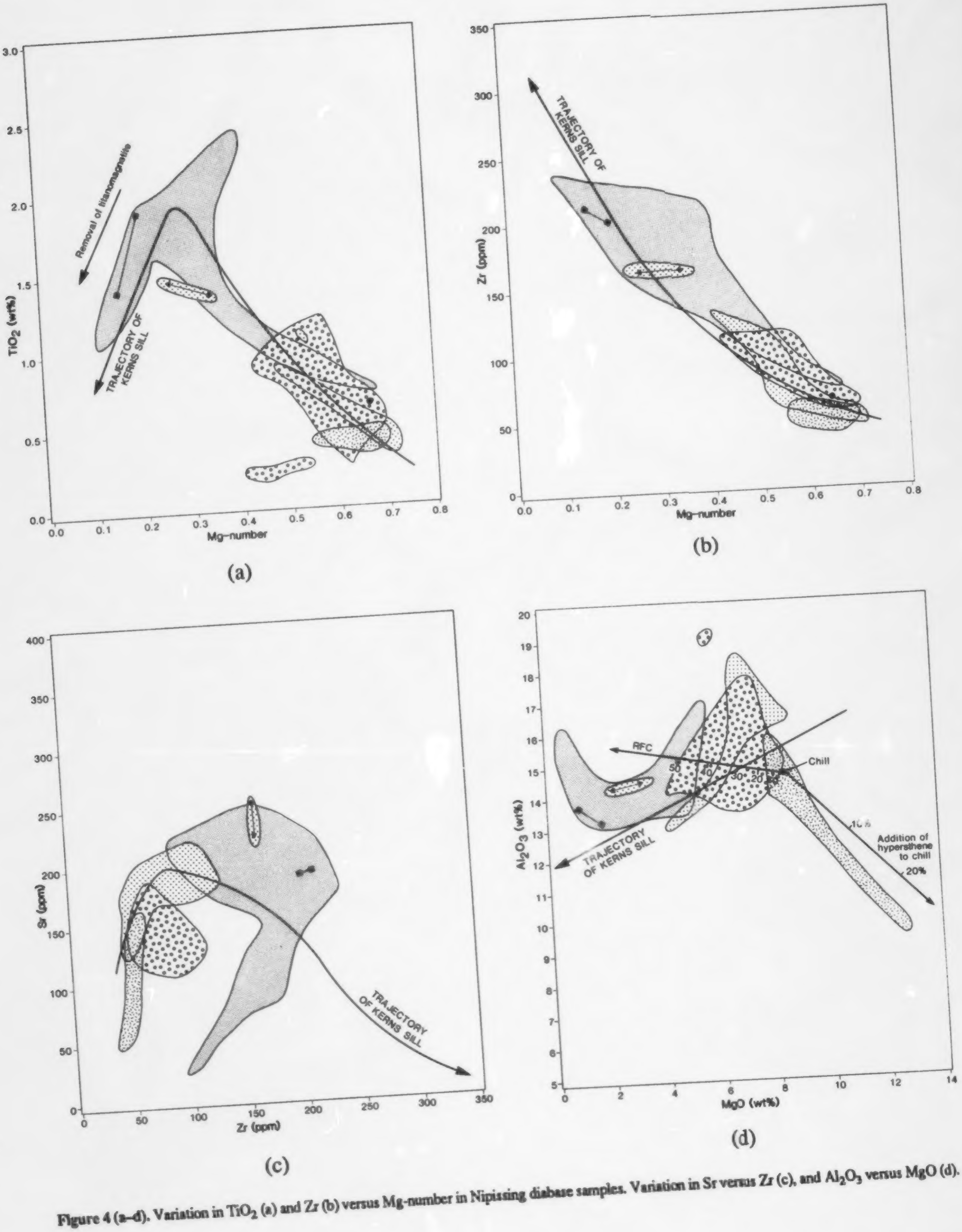
Figure 3. AFM diagram showing major element features of the Nipissing rocks, including the calc-alkaline enrichment pattern of the more differentiated lithologies, and the effect of control by sulfide.

These differences in silicate geochemistry are significantly larger than would be accounted for by the dilution effect introduced by the small proportion of sulfides present in these samples (<5%). It would therefore appear that the sulfide bearing diabases are more mafic (higher MgO and modal hypersthene). Importantly, the hypersthene diabases from the Wanapetei intrusion (which hosts the Rathbun Lake showing, carrying 10 ppm Pt and 30 ppb Pd), also have significantly higher MgO (up to 12.2 wt.%: Dressler 1982) and lower Al_2O_3 (as low as 12.9 wt.%: Dressler, 1982) than samples which would fall on an extension of the Kerns Sill trajectory. As both the Wanapetei intrusion and Kukagami Lake sill carry sulfides enriched in nickel, copper, gold and the PGE, it is suggested that the major and trace element data may have some value in exploration for magmatic or hydrothermal nickel, copper, gold and PGE deposits in the Nipissing diabase province.

IMPLICATIONS FOR PLATINUM GROUP ELEMENT POTENTIAL

Abundances of platinum (Pt) and palladium (Pd) at the Rathbun Lake sulfide showing of the Wanapetei Intrusion are some of the highest known to be associated with mafic rocks. The observation that globules of differentiated magmatic sulfide are developed in the hypersthene diabase provides some of the first strong evidence for a magmatic origin (Lightfoot 1987), rather than the conventional hydrothermal origin (Rowell and Edgar 1986). The presence of disseminated sulfide in the hypersthene diabase of the Kukagami Lake sill, which is believed to be along strike from Rathbun Lake in the same intrusive body, suggests that the development of magmatic sulfide mineralization was not limited to just the Rathbun Lake occurrence.

The Kukagami Lake occurrence has high Au, Pt, and Pd values (<600 ppb Au, <1100 ppb Pt, and <4160 ppb Pd) in rocks which contain less than 5% sulfide, which compares to <4440 ppb Au, <34 500 ppb Pd, and <3050 ppb Pt in the massive sulfides (<75% sulfide) at the Rathbun Lake occurrence.



(a)

(b)

(c)

(d)

Figure 4 (a–d). Variation in TiO_2 (a) and Zr (b) versus Mg-number in Nipissing diabase samples. Variation in Sr versus Zr (c), and Al_2O_3 versus MgO (d).

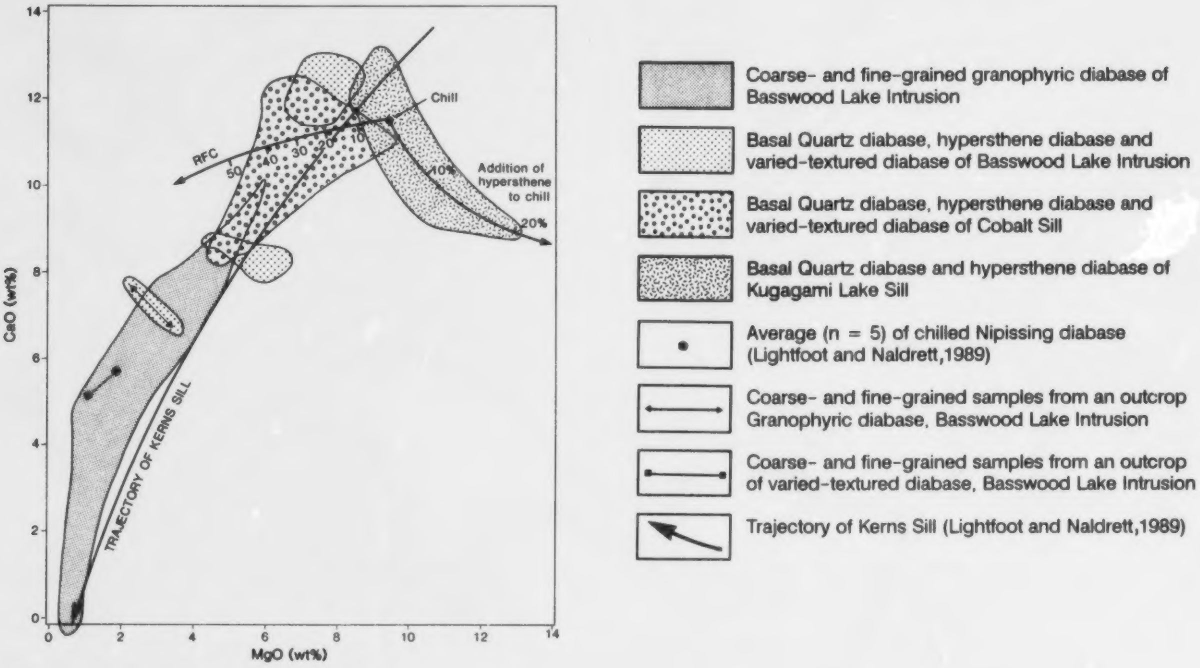


Figure 4(e). Variation in CaO versus MgO (e).

The basal quartz diabase, hypersthene diabase, and basal chilled margins of Nipissing intrusions all develop from a magma type which has seen the introduction of a contribution from the continental crust. Irrespective of whether the process which introduced the material took place in the crust or mantle, the addition of crustal silica to an ultramafic magma will influence the potential for the magma to segregate magmatic sulfides (Irvine 1975). The Nipissing magma type is comparable in rare earth element (REE) characteristics to many of the flood basalt lavas which have a significant contribution from the continental crust, and this similarity suggests at least the possibility that magmas carrying a signature from the continental lithosphere may be more likely to host mineralization. The observation that many of the most contaminated flood basalt magmas are also the most depleted in Ni, and Cu (e.g. Naldrett et al., in prep.) then becomes important. The average unmineralized quartz diabases and basal chills carry 123 ppm Ni, and 134 ppm Cu, and 138 ppm Ni, 98 ppm Cu, respectively. These figures are much higher than many flood basalts (which have similar Mg-number). For example, values of <50 ppm Ni, and <100 ppm Cu are found in heavily contaminated flood basalts from the Siberian Traps (which are associated with unmineralized intrusions), whereas less contaminated Siberian Trap lavas (associated with mineralized intrusions) have Ni and Cu values more comparable to the Nipissing diabase (Lightfoot et al. 1990). Sulfide segregation may be influenced by both assimilation of crust and fractionation of magma. Both processes are capable of producing the increase in SiO_2 required to saturate the magma in S, and trigger segregation of sulfides. Roof-zone granodiorites from the Obabika sill at the northwestern end of Lake Temagami (Lightfoot and Naldrett in prep.), and from the Kerns sill (Lightfoot and Naldrett 1989) contain <5% disseminated sulfide with Au <35 ppb, Pd <339 ppb, and Pt <221 ppb. Presumably the elevated values reflect the concentration of these elements in residual liquid, and the late-stage fractionation of sulfide which concentrates the noble metals.

SUMMARY

1. Geochemical variations within Nipissing intrusions are controlled dominantly by low pressure fractional crystallisation which is coupled to assimilation of roof sediments (Lightfoot and Naldrett 1989). Some intrusions have readily assimilated their roofs, and the degree of assimilation appears to depend on the geometry of the intrusions and the nature of the sediment.

2. Major and trace element compositional data confirm that early orthopyroxene accumulation accounts for compositional variations in the more mafic lithologies of the Kukagami Lake sill.

3. Compositional data for chilled margins and undifferentiated Nipissing intrusions suggest that the parental magma was extremely uniform in composition throughout the province (Lightfoot et al., in prep.). This in turn suggest that the source or processes governing the composition of the magma were the same throughout a 500 km long basin. The variation in style of mineralization may therefore have a more local control.

4. Major and trace element data indicate that the low Ti and high LILE reflect the addition of a component from the continental crust. The variations in the Nipissing chill are reproduced by the addition of just a few percent sediment to a primitive mantle source. It is suggested that the homogeneity of the magma across the province would best be explained by the tapping of a reasonably well mixed source containing a crustal contribution, rather than by assimilation of crustal material by the magma en-route from the mantle to the crust (Lightfoot et al., in prep.).

5. The potential for magmatic sulfide mineralization enriched in Cu, Ni, and the PGE appears to be highest in intrusions which have differentiated to produce the most mafic (hypersthene-rich) lithologies. The Kukagami Lake sill and the Wanapetei intrusion, which may be part of the same body, have modal abundances of hypersthene cumulates approaching 20%, and elevated MgO and depleted CaO, Al_2O_3, and Sr. These features may be indicative of intrusions which are likely hosts to mineralization.

ACKNOWLEDGMENTS

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46. Project Unit 91–16. Report on the Joint Ontario Geological Survey—Ryerson Polytechnical Institute Spectroscopic Initiative Project

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INTRODUCTION

The joint Ontario Geological Survey–Ryerson Polytechnical Institute Spectroscopic Initiative Project began in September 1990. The aims of the project were to review, and if necessary revise, certain procedures within the Geoscience Laboratories and to assist in the education of young analysts. The project was especially timely as six Ministry employees had recently retired and the presence of the students allowed several small tests to be undertaken or procedural documentation assessed while the positions were being filled. An additional benefit was the unexpected boost to morale in the laboratory.

The project also corresponded with the release of the second edition of the Geoscience Laboratories Procedural Manual (OGS, 1990). The students tested the procedures by following them with little input. The resulting clarifications and additions ensured that the written documentation for the laboratory procedures are truly easy to follow and clear.

In total, four BSc theses were completed by the students in the Spectroscopy and Mineral Sciences subsections of the Geoscience Laboratories. Several spectroscopic techniques were utilized: X-ray fluorescence (XRF), X-ray diffraction (XRD), inductively coupled plasma mass spectrometry (ICP-MS) and flame photometry (FM). Specifically, Ba was determined by XRF, a sample-preparation method was evaluated by ICP-MS, Na and K were determined using FP and the comparison of calcite/dolomite determination by a classical wet-chemical method was compared to that possible by XRD. All four projects were successfully completed and the theses are available in the Geoscience Laboratories and OGS library for consultation.

PROJECT DESCRIPTIONS

Analysis of Ba in Geological Samples by X-Ray Fluorescence by R. Isla

Although Ba can be determined by atomic absorption spectroscopy, detection of Ba by XRF is particularly appropriate as samples containing over 200 ppm Ba or barite tend to be insoluble and therefore not well determined in sample prepared by acid digestion techniques. The results of this study indicate that Ba can be successfully determined in a variety of geological materials containing 20 to 5000 ppm Ba. Typically, relative measurement and counting uncertainties decrease with the concentration of Ba in the sample. Sample preparation is straightforward and identical to that used for the existing T3 trace-element package as used at OGS.

A Modified Method for the Determination of Trace Elements in Geological Materials by Inductively Coupled Plasma Mass Spectrometry by L. Duong

The determination of elemental abundances in geological materials by inductively coupled plasma mass spectrometry requires that the samples are digested using a complicated, time-consuming acid procedure. Prior to this study, this process required three days. In terms of fumehood scheduling, technician availability and sample throughput, it was desirable to reduce this time as much as possible without compromising the integrity of the digestion.

The digestion procedure outlined in the OGS lab manual (OGS, 1990) was revised to allow treating the first and second digestion stages in one day rather than spread out over two days. International and in-house reference materials were used to represent typical samples. Statistical F and T tests were performed on the results to ensure that the two populations of data were statistically indistinguishable. Table 1 lists the percent error of the mean (a measure of accuracy) of the determinations. Although some analytes which are close to the detection limit have somewhat poorer accuracy measures (e.g., Sr in AC-E, Table 1), the average uncertainty for all elements tested on the range of geological materials tested was 4.09%. Thus analytical results determined by the revised experimental method met the Geoscience Laboratories' quality control standards in terms of accuracy. The new digestion procedure is in use.

Evaluation of Na and K Detection Using Flame Photometry by S. Tress

Flame photometry is used in geoanalysis to determine elements such as Na, K, Li and Ca in a rapid, interference-free manner. The instrument has a wide dynamic range (11 orders

Table 1. Percent error of the mean (a measure of accuracy) of the determinations of the analytes of the T5 package in selected international and in-house reference materials.'

Reference Material	Rb	Sr	Zr	Nb	Cs	Hf	Ta
MRB-29	[illegible]	4.18	2.28	2.84	9.61	1.88	7.78
SY-2	0.3[illegible]	0.28	2.47	4.37	2.16	5.70	5.16
MGR-1	6.9[illegible]	5.15	2.45	7.50	2.35	3.99	3.02
AC-E	0.49	11.41	2.73	4.49	1.61	4.46	4.62
Average (%)	3.00	5.20	2.48	4.80	3.93	4.01	5.14

of magnitude) and high sensitivity. Low elemental concentrations of Na and K can be readily measured. The current OGS flame photometer method for the determination of these elements in geological material was assessed, revised, validated and documented. Elemental concentrations were determined for Na and K in standard and in-house reference materials. The characteristics of new flame photometers were tested to allow a detailed evaluation of those instruments currently on the market

Comparison of Calcite/Dolomite Ratios by Chittick Analysis versus X-Ray Diffraction by R. To

Till samples were analyzed by both Chittick and XRD to allow a comparison of calcite/dolomite ratios. The agreement between the two methods is good. The precision of the XRD method can be improved considerably if the sample is loaded in a manner to avoid preferred orientation.

BENEFITS FOR THE ONTARIO GEOLOGICAL SURVEY

The benefits that arose for the OGS included the actual evaluations and written theses (typically, implementation of changes to methods). For example, method development is now completed to facilitate the addition of Ba to the XRF T3 package. This will be initiated in Sudbury. The ICP-MS sample-preparation evaluation exercise has meant that sample preparation time has decreased by 33%; thus 180 samples can be prepared weekly, increasing the laboratories's capacity to deliver this frequently requested package. This revision is now currently utilized. The flame photometry project for the determination of Na and K has meant that new standards were prepared and quality control confirmed. A new technician learned the revised method and routinely performs these determinations. Progress has been made on the determination of calcite/dolomite ratios; further avenues of possibilities have opened.

CONCLUSIONS

Overall, the projects contributed to the Laboratories' geoanalytical expertise in a cost-effective manner. The project results and revisions were integrated into the routine functioning of the laboratory. The students' experience in the laboratory was satisfactory as well—four young analysts received education in spectroscopic techniques and experience in a functioning laboratory.

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47. Project Unit 91–16. Technology Transfer: Where do Great Ideas in ICP Design Get Tested? At MNDM's Geoscience Laboratories!

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WHAT IS TECHNOLOGY TRANSFER?

There are several geologically important elements that have traditionally been either difficult to determine, determined by labour intensive procedures, or determined sequentially. To alleviate this, the Geoscience Laboratories has contributed to the development of new or new-to-geoanalysis techniques by providing a less formal testing ground for new instruments in a professional laboratory setting.

Such technology development and transfer consists of:

1. INSPIRATION - conception of an idea and design of the equipment or procedure,
2. TESTING - testing of the technology for both general and specific applications,
3. COMMUNICATION - communication of results, and
4. USE AND APPLICATIONS - development and dissemination of applications and acceptance of data.

Typically, the initial development work characterized by step 1 is done in the private sector (i.e. production of a prototype instrument as in the case, for example, of the Ontario-based technology which produced the Elan 250 ICP–MS or the Leco Plasmarray). Step 2, the subsequent testing (either general or specific), is done as a collaborative effort between Geoscience Laboratories and the private company. Smaller modifications or supporting procedures, which can be critical to performance or enhance the suitability of the instrument for a specific application, can evolve at this collaborative stage (e.g. blunt skimmers, Doherty 1990a). The results of such technology transfer projects are communicated (step 3) in professional journals (Doherty and Vander Voet 1985; Riddle et al. 1988; Doherty 1989), theses (Doherty 1990a; Duong 1991; Isla 1991; Tress 1991), orally in conference presentations (Doherty 1990b), Ministry publications (Richardson et al. 1990a), by phone consultation and informally in meetings. The changes in technology are implemented by the manufacturer and in other laboratories (e.g. Hall and Pelchat 1990; Hall and Plante 1990). The transfer is complete when data generated by these procedures are used by the client groups (step 4).

FOR EXAMPLE

Technology transfer such as that outlined here has helped launch two (then small) Ontario high technology firms into the highly competitive analytical market (e.g. Sciex Elan ICP–MS in 1984 and PRA–Leco Instruments Limited Plasmarray ICP–OES in 1988). This type of collaboration directly supports the development of the Ontario analytical industry and is of direct benefit to the geoanalytical community (and thus to mineral exploration and geochemical mapping programs) because early modifications made to software or instrument design can optimize the usage for specific applications.

For example, the application of inductively coupled plasma mass spectrometry (ICP–MS) to geoanalysis has been well documented (Beneteau et al. 1991a; Riddle et al. 1988; Doherty and Vander Voet 1985). Since 1984, the Geoscience Laboratories staff have assisted in the transfer of ICP–MS technology from the private sector to the analytical community. This has contributed to the sale of over 100 instruments and multimillion dollars worth of business to Sciex, an Ontario-based high technology company. Government, private industry and university laboratories have purchased ICP–MS systems, for instance, X-ray Assay Laboratories, Acme Laboratories, Falconbridge Limited, Geological Survey of Canada, Toronto General Hospital and McMaster University are among the many users of this technology.

Modification to the ICP–MS

Significant fundamental design changes have occurred as a result of work done by Will Doherty, ICP Scientist and Geoscientist, in the ICP Laboratory of the Geoscience Laboratories, Ontario Geological Survey (OGS). Specifically, understanding of the physics of plasma sampling and the detector electronics of the ICP–MS has resulted in the redesign of parts of the sample introduction system and the detector (Doherty 1990a). These improvements have resulted in a cost-saving for the OGS, with respect to consumables, and a lowering of the detection limits for rare earth element analysis by 70%. Furthermore, these design changes were incorporated by Sciex in the Elan ICP–MS.

LECO Plasmarray

Developmental work with LECO Instruments Limited on the Plasmarray ICP-OES instrument resulted in the collection of elemental spectral data in complex matrices at an analytical resolution never before possible. Such data, applicable to all inductively coupled plasma-optical emission and atomic absorption spectrometers, forms a vital tool for use in the identification of spectral interferences and is being prepared for publication.

Ru-Re Internal Standardization Procedure

A dual internal standardization procedure developed in the Geoscience Laboratories of the OGS by Doherty (1989) is in use at the Geological Survey of Canada Analytical Laboratories (Hall and Pelchat 1990). Other procedural documentation and intermethod (ICP–XRF) quality assurance programs are also publicly available (Geoscience Laboratories 1990; Richardson et al. 1990a, 1990b).

HOW DOES "TECHNOLOGY TRANSFER" FIT INTO THE MANDATE OF A GOVERNMENT LABORATORY?

Divisional and Ministry Goals

Technology transfer is part of the 40% applied research that complements the Geoscience Laboratories' primary mandate of providing high quality geoanalytical data to client groups (geologists in the Ministry and the minerals industry). Overall, this applied research is compatible with the divisional goals:

1. To provide comprehensive and accessible information on the geological environment for mineral exploration, land use planning and management.
2. To promote Ontario's mineral potential and support the marketing of mineral products, technological expertise and services.

and the branch goals:

1. To develop new survey, research and analytical techniques in support of geoscience program.
2. To provide for the identification and analysis of mineral, rock and ore samples.

Under these umbrellas, the objective of applied research in the Geoscience Laboratories is to ensure that the analytical capabilities of the Geoscience Laboratories match the analytical requirements of the clients by anticipating, or responding to, demands for new or improved methods.

Management Board of Cabinet Policy Statement

This type of technology transfer program is sanctioned by the Policy Statement regarding the corporate role of government laboratories that was issued by Management Board of Cabinet. The mission statement for the Government's laboratories indicates that there are five principles that guide the program development in such laboratories (Management Board of Cabinet 1991).

1. Technology transfer programs help maintain the STRATEGIC POSITIONING of the Geoscience Laboratories with respect to geoanalysis as the staff provide support through the conduct of applied research in methodology development.
2. The PARTNERSHIPS (COLLEGIALITY) aspect of the laboratory's mandate is promoted by contact with private sector facilities. This acts to provide laboratory personnel with the information necessary to develop and monitor the delivery of testing services.
3. Further, the Ministry of Northern Development and Mines' COMMITMENT TO LONG TERM PLANNING via technological development and transfer has meant that the Geoscience Laboratories can maintain an efficient operation in which long term strategic implications are considered while the Laboratories respond to short term resource pressures.
4. Over time, this commitment has sustained scientific expertise in the Laboratories and has provided for a HUMAN RESOURCE MANAGEMENT INCENTIVE: the provision of an environment that promotes scientific pursuit and rewards exceptional achievement.
5. Finally, the foregoing means that staff of the Geoscience Laboratories are able to meet the first objective of the policy statement requires that the Ontario Government laboratories be sites of EXCELLENCE AND MAINTAIN THE PUBLIC TRUST through adaption, innovation and the pursuit of excellence. The staff therein are also able to advise, audit, and regulate the private sector laboratory community and provide advice to senior officials.

Thus, these activities of the ICP laboratory of the Geoscience Laboratories conform to Ontario Government policy, the 1988 Activity Review by Management Board Secretariat and the Ministry of Northern Development and Mines objectives. The essential role of research and development is recognized by management and encouraged at the Geoscience Laboratories by participation in the transfer of analytical advances.

RECOGNITION OF EMPLOYEE CONTRIBUTIONS TO TECHNOLOGY TRANSFER

Will Doherty, ICP scientist and Geoscientist IV in the Spectroscopy subsection, has been especially active in furthering technological development and transfer. In recognition of this, he has recently been awarded several honours and/or awards. In 1989, he was appointed Geoscientist IV within the Ontario Geological Survey for an eighteen month period. In the spring of 1990, he received an award for analytical excellence from the Analytical Laboratory Council, an administrative organization that links nine Province of Ontario Laboratories. Finally, he was granted the prestigious Barringer Award of the Spectroscopy Society of Canada at their 1991 annual meeting. Thus, his high quality of work, which is done within the confines and principles that are described here, is recognized by our Ministry, the Province of Ontario, the scientific community as well as the firms to which the technological developments are passed.

SUMMARY

This technology transfer program directly benefits the manufacturers of Ontario-based technology, with feed-back of technological developments into the Ontario minerals industry. It allows the Geoscience Laboratories of the Ontario Geological Survey to keep pace with developments in geoanalytical methodologies and their applications, anticipate and respond to demands for improved procedures, and develop its capabilities accordingly.

THE FUTURE

Upcoming initiatives in the ICP laboratory include analysis of solid samples by laser ablation ICP–MS (Beneteau et al. 1991b) and the development of a platinum group element package for ICP–MS. On the basis of this on-going technology transfer program, the staff of the Spectroscopy subsection of the OGS act in a geoanalysis and geochemical consulting capacity for geologists and geoanalytical facilities (companies, federal government, universities) and are involved in the transfer of knowledge, standards and information. This insures that leading-edge knowledge and excellence in science and geoanalytical research is accessible, fully integrated and rapidly disseminated to the client group, the service geoanalytical industry, universities and the geological and mining communities.

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48. Project Unit 91–16. Automated Sample Preparation for X-Ray Fluorescence Analysis

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INTRODUCTION

X-ray fluorescence (XRF) is a well-established analytical technique that is used to provide the "major elements" (Si, Ti, Al, Ca, Na, Mg, Mn, K, P, Fe) composition of rocks. Sample preparation for this procedure involves mixing approximately 1 g of rock powder with 10 g of reagents (flux, matrix modifier and wetting agent). This mixture is melted and homogenized in a platinum-gold crucible over a natural gas-air-oxygen burner. The molten sample is then cast into a mould or casting dish, allowed to cool and form a glass disk, affixed with a label, and then the resulting disk is analyzed by XRF. The data generated by this process is typically used to define and classify rock units. Data is manipulated either manually or using computer programs, such as Triangle© for LOTUS 1-2-3® (Mustard and Richardson 1990) or the Ontario Geological Survey's PETROCK© package.

To take advantage of the high level of safety, reproducibility and time and cost savings offered by the Leco Instruments Ltd. FX200 fluxer, XRF sample production was automated at the Ontario Geological Survey. This fluxer can automatically prepare 6 samples at a time and produce 96 glass disks per day. This is a 100% improvement over the manual method used previously. Sample size and, thus, amounts of reagents necessary were decreased by 25%.

The FX200 fluxer was designed, built and patented by Stelco Steel Ltd., Metallurgical Department, Hamilton, Ontario, in 1984. It is now produced and marketed under licence by Leco Instruments Ltd. in Mississauga, Ontario. Stelco Steel Ltd.'s original application for the fluxer was to fuse samples of steel slag prior to the analysis of Fe, Ti, Cr and Ni by XRF. Currently, there are also fluxers at the Ministry of the Environment's Industrial/Domestic Waste Unit's laboratory in Rexdale; Inco's laboratories in Sheridan Park, Sudbury, and in Port Colbourne; Mineral Sciences Division, CANMET, in Ottawa; Falconbridge Mines in Sudbury and X-ray Assay Laboratories in Toronto. The development and use of such a device in both private and government laboratories and in private companies is an excellent example of successful technology transfer occurring in Ontario.

DESCRIPTION OF THE FLUXER DEVICE AND THE FUSION PROCESS

The Leco Instruments Ltd. FX200 fluxer is a device which heats rock powders and reagents (lithium tetraborate, lanthanum oxide and ammonium iodide) to produce glass disks for XRF analysis. At the Ontario Geological Survey, detailed instructions for operation are outlined in Procedure EA6 (OGS 1990). In summary, the fusion process involves melting 1.25 g of the rock powder with about 6.15 g of lithium tetraborate, 0.747 g lanthanum oxide and 0.2 g ammonium iodide. Thus each bead consists of about 15% rock powder. The sample and reagents are placed in platinum crucibles that can withstand temperatures of up to 2500°C. The crucible is heated by flames from burners that are fuelled by a mixture of natural gas, liquid oxygen and air. The average temperature of the burners is 1510 ±10°C and this must be adjusted by the manufacturers' personnel. Fusion temperatures (in the crucible) average 1300°C. Six beads are prepared simultaneously. The fluxer can also be used to generate a fusion melt that is poured into beakers and dissolved. This capacity is not used routinely by the Ontario Geological Survey at present. Specifications for regular use are listed in Table 1.

Manual fusion is less efficient, more dangerous and not as reproducible. Only 2 samples can be processed when the procedure is performed manually. The manual fusions are done in an open fume hood over a Bunsen burner with the crucible balanced on a metal ring. Manual agitation occurs approximately once every 5 minutes.

Mechanical Advantages

Many of the advantages of this instrument, determined during its evaluation period and first year of operation, were structural in nature. The mechanical reproducibility is excellent during casting. The molten glass consistently pours smoothly from the crucible into the mould, and no adjustments are required even after long-term use; "spills" have never occurred. Loading and unloading of the crucibles and moulds is easy. The holders for the platinum-ware have remained solid and fixed. The bar in which the moulds are supported is, and has remained, level. Thus, disks are never rejected because of uneven surfaces. The bar and crucible supports have not deformed in the extreme heat generated by the burners. Crucibles and moulds have not sustained damage that could be traced to fluxer design. The agitation action remains smooth.

Procedural Advantages

Unlike manually made disks, the top surface (meniscus) of the disks made by the fluxer have a sharp edge. This is perhaps due to the fact that the platinum mould does not get as hot during fusion as it does during manual sample prepara-

Table 1. Instrument specifications.

Crucible (high form)	platinum-gold alloy (95% Pt:5% Au) 35 mm x 37 mm (top) x 20 mm (bottom) not dimple-bottom
Crucible Volume	35 mL
Crucible Capacity	15 g powder
Casting Dish (mould)	platinum-gold alloy (95% Pt:5% Au) 44 mm diameter x 8 mm deep
Casting Dish (volume)	7.5 mL
Disk Size (typical)	35 mm diameter x 6.35 mm thick
Beaker Capacity	200 mL, tall form
Beaker Stirring	magnetic
Burner Output	15 000 Btu/burner
Burner Gas Consumption	95 ft^3/burner
Burner Temperature	adjustable to 1750±10°C (3128°F)
Fusion Temperature	1300°C (2192°F) in crucible

tion. The presence of a sharp edge on the disk means that top and bottom surfaces cannot be analyzed and, thus, are not interchangeable. Air bubbles did not form on the mould surface, and the sample didn't remain as a mass in the crucible when ammonium iodide was used as a wetting agent.

Programming Considerations

Fluxer programming is straightforward. Changes are easily made using the on-board microprocessor unit. Fuel costs are minimized by the operator as the number of burners used at any time can be programmed. The fluxer has programmed diagnostics which inform the operator if certain conditions are not met (e.g., event of power failure or lack of oxygen). This allows unattended operation. At intervals in the operational program, the fluxer can be made to create an audible tone to inform the operator of the status of the cycle. This is useful when the attendant is performing other duties. A typical operational program is listed in Table 2.

Preprogrammed options are easily selected on the fluxer and provide reproducibility, flexibility, save time and eliminate unnecessary procedures. The manual-operation mode is useful for initial programming and allows the definition of parameters for use with the automatic mode. Manual operation also provides flexibility for processing unusual samples.

Safety Considerations

Safety considerations are paramount in the Geoscience Laboratories Section. The fluxer design is inherently much safer than the manual setup. Other safety features include automatic burner ignition; when necessary, this can be overridden and the burners lit manually with a piezoelectric lighter. Additionally, the use of a natural gas-oxygen-air mixture has proven to be safe and convenient while still providing the high temperatures required for proper fusion. Propane can also be used.

On the recommendation of Envirotest, an industrial hygienic company, the emissions of nitrous oxide and nitrogen dioxide generated at the edge of the device that vents the fluxer has been monitored. Results to date indicate that levels are under the recommended time-weighted average exposure level of 25 ppm for NO and 3 ppm for NO_2. However, experience over the last 18 months has proven that the fluxer can operate reliably with limited attention. As a result, current practice is to work in an adjacent room while the fluxer is operating, especially during the initial heat-up step when NO and NO_2 are released from the crucibles. The fluxer produces significant quantities of heat (90 000 British thermal units) when operational. This has been minimized by proper design of air flow through the overhanging venting device.

APPLICABILITY OF THE FLUXER TO GEOLOGICAL SAMPLE PREPARATION

Homogeneity and Sample Dissolution

The XRF analysis is used to provide the "major elements" (Si, Ti, Al, Ca, Na, Mg, Mn, K, P, Fe) composition of samples. Due to fundamental aspects of XRF theory (e.g., depth of penetration of X-rays), it is critical that the sample surface presented to the XRF instrument is homogeneous, bubble and ripple free, totally flat and free of contaminants. These requirement are met by the fluxer in two ways. Firstly, because of the unique agitation action and the high temperatures utilized, the sample is completely melted and then quenched, resulting in a homogeneous disk. These features are especially important in the analysis of geological material as they promote the complete dissolution of refractory minerals such as zircon, chromite and cassiterite by ensuring prolonged, high-temperature contact between the sample and the flux. Thus, the quality of the disks prepared is consistently homogeneous and defect free. Secondly, the construction of the crucible and mould supports are such that even with a year of use on a routine basis there is no sag or deformation evident, and flat disks are still produced.

Table 2. Typical operational program.

Low heat	6 minutes
High heat with agitation	18 minutes
Cast	0 minutes 15 seconds
Cool	0 minutes 10 seconds

Table 3. Compiled data and statistics for samples and reference materials prepared manually as 40 mm disks and in an automated fashion using the fluxer. More discussion of the data is available in the text.

PART A: Data Comparison		Size (mm)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO
LP-123	Automated	40	36.7	8.10	15.9	14.3	14.9	0.65	0.15	3.56	0.00	0.16
LP-123	Manual	40	36.7	8.14	16.1	14.4	14.7	0.75	0.15	3.56	0.00	0.16
LP-124	Automated	40	43.3	2.18	8.19	47.5	0.00	0.00	0.00	0.09	0.00	0.08
LP-124	Manual	40	43.7	2.19	8.39	47.5	0.05	0.00	0.00	0.09	0.00	0.07
LP-125	Automated	40	47.5	6.08	11.8	26.8	7.22	0.38	0.00	0.38	0.00	0.18
LP-125	Manual	40	47.6	6.06	12.1	26.6	7.18	0.35	0.00	0.38	0.00	0.18
LP-126	Automated	40	71.3	12.0	2.62	0.17	1.18	3.35	2.11	0.41	0.00	0.06
LP-126	Manual	40	71.1	12.0	2.64	0.14	1.16	3.43	2.11	0.41	0.00	0.06
LP-127	Automated	40	69.4	15.1	1.48	0.39	0.88	3.55	2.69	0.08	0.00	0.09
LP-127	Manual	40	69.4	15.0	1.55	0.42	0.87	3.53	2.70	0.11	0.00	0.09

PART B: Accuracy		Size	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	AVE[4]
SY-2	Accepted[1]		60.07	12.2	6.32	2.66	8.03	4.37	4.52	0.15	0.44	0.32	
(SRM)	Manual	40	60.0	12.3	6.09	2.81	8.03	4.26	4.53	0.17	0.44	0.32	
(Syenite)	Automated A	35	59.5	12.1	5.70	2.79	8.06	4.02	4.27	0.09	0.41	0.31	
	Accuracy M(%)		-0.12	0.82	-3.64	5.64	0.00	-2.58	0.22	13.33	0.00	0.00	±2.63
	Accuracy A(%)		-0.94	-0.82	-9.81	4.89	0.37	-8.01	-5.53	-40.00[3]	-6.82	-3.12	±4.48
	Automated B	35	59.1	11.9	5.66	2.85	8.04	3.98	4.13	0.09	0.42	0.31	
	Inst.Cont.Avg.	35	59.9	12.05	6.23	2.62	7.98	4.27	4.56	0.12	0.47	0.32	
	Accuracy(%)		-0.28	-1.23	-1.42	-1.50	-0.62	-2.29	0.88	-20.00[3]	6.82	0.00	±1.67
MRG-1	Accepted[1]		39.2	8.51	17.9	13.5	14.7	0.72	0.18	3.69	0.08	0.17	
(SRM)	Manual	40	38.1	8.19	16.8	13.7	15.2	1.02	0.22	3.67	0.05	0.16	
(Gabbro)	Automated A	35	35.6	8.06	15.8	14.1	15.3	0.62	0.13	3.55	0.01	0.16	
	Accuracy M(%)		-2.81	-3.76	-6.15	1.48	3.40	41.67[3]	22.22[3]	-0.54	-37.53	-5.88	±3.43
	Accuracy A(%)		-9.18	-5.29	-11.73	4.44	4.08	-13.88[3]	-27.78[3]	-3.79	-87.53	-5.88	±6.34
	Automated B	35	36.8	8.11	1.59	14.1	15.5	0.46	0.12	3.59	0.01	0.16	
	Inst.Cont.Avg.	35	39.37	8.52	17.6	13.3	14.6	0.88	0.19	3.73	0.07	0.17	
	Accuracy(%)		0.43	0.12	-1.68	-1.48	-0.68	22.53[3]	5.56[3]	1.08	-12.53	0.00	±0.78
MRB-10	Accepted[2]		39.3	2.10	7.48	38.7	0.05	0.00	0.00	0.10	0.02	0.07	
(IHR)	Manual	40	38.4	1.94	7.53	39.8	0.00	0.00	0.00	0.09	0.00	0.06	
(Peridotite)	Automated A	35	37.1	1.88	7.02	40.0	0.04	0.00	0.00	0.08	0.00	0.06	
	Accuracy M(%)		-2.29	-7.62	0.67	2.84	-100.00[3]	0.00	0.00	-10.00[3]	-100.00[3]	-14.28[3]	±2.24
	Accuracy A(%)		-5.60	-10.48	-6.15	3.35	-20.00[3]	0.00	0.00	-20.00[3]	-100.00[3]	-14.28[3]	±4.26
	Automated B	35	37.5	1.94	7.04	39.8	0.07	0.00	0.00	0.08	0.00	0.06	
	Inst.Cont.Avg.	35	39.0	2.05	7.50	37.7	0.06	0.00	0.00	0.10	0.01	0.09	
	Accuracy(%)		0.76	-2.38	0.27	-2.58	20.00[3]	0.00	0.00	0.00	50.00[3]	28.57[3]	±0.86
MRB-13	Accepted[2]		40.8	1.31	53.4	1.09	1.03	0.44	0.82	0.07	0.20	0.04	
(IHR)	Manual	40	40.2	1.03	53.1	1.00	0.88	0.14	0.84	0.03	0.15	0.04	
(Banded	Automated A	35	39.4	1.09	51.5	1.00	0.90	0.00	0.80	0.02	0.15	0.04	
Iron	Accuracy M(%)		-1.47	-21.54	-0.56	8.26	-14.56	-68.18[3]	2.44	-57.14[3]	-25.00	0.00	±9.23
Formation)	Accuracy A(%)		-3.43	-16.79	-3.56	-8.26	-12.62	-100.00[3]	-2.44	-71.43[3]	-25.00	0.00	±9.01
	Automated B	35	39.8	1.10	51.6	1.00	0.89	0.11	0.80	0.02	0.15	0.04	
	Inst.Cont.Avg.	35	40.95	1.31	54.0	1.10	0.85	0.00	0.84	0.08	0.20	0.04	
	Accuracy(%)		0.37	0.00	1.12	0.92	-17.48[3]	-100.00[3]	2.44	14.29[3]	0.00	0.00	±0.69

PART C: Precision

BAS-55	(IHR) (Basalt)	35	49.60	12.731	3.48	6.10	9.21	2.41	0.73	1.91	0.24	0.18	
σn-1	(Abs Std Dev)		0.35	0.11	0.06	0.11	0.09	0.12	0.02	0.06	0.01	0.005	
RSD%	(Abs Std Dev)		0.71	0.88	0.47	1.79	1.05	4.93	2.56	3.14	4.66	2.77	2.30%
MRG-	(SRM) (Gabbro)	35	39.37	8.52	17.61	3.31	4.6	0.88	0.19	3.73	0.07	0.17	
σn-1	(Abs Std Dev)		0.29	0.03	0.07	0.26	0.09	0.12	0.01	0.09	0.01	0.005	
RSD%	(Abs Std Dev)		0.74	0.35	0.38	1.96	0.65	13.09	6.86	2.60	17.99[3]	3.22	3.32%

1) Govindaraju 1989
2) OGS (1990)
3) At XRF Determination Limit
4) Accuracy calculated using only analytes above determination limit.

IHR	*Inhouse reference material*
SRM	*Standard reference material*
Inst.Cont.Avg.	*Instrument control sample, averaged valued*

Although it is difficult to quantify the consistently much superior quality of the disks that are made by the fluxer, it is possible to illustrate how comparable the data generated by the FX200 disks are to those produced manually (Table 3, part A). The LP-series samples were made both manually, in 40 mm moulds, and using the fluxer and these were then analyzed using an XRF calibration for major elements that was established using standard reference materials (SRM) made up as 40 mm disks. The comparison is obvious *(see* Table 3, part A).

The data from reference materials SY-2 (syenite), MRG–1 (gabbro), MRB-10 (peridotite) and MRB-13 (banded iron formation) illustrate the important interdependence among disk shape, disk form and calibration (*see* Table 3, part B). For each of the reference materials, the accepted values are listed (*see* Table 3, part B, data in rows entitled "accepted"). Prior to analyzing the set of manually made, 40 mm disks (*see* Table 3, part B, data reported in rows entitled "Manual") and 35 mm disks made automatically (*see* Table 3, part B, data in rows entitled "Automated A" and "Automated B"), the XRF instrument was calibrated using SRM fused into 40 mm disks. The accuracy of the resulting data are tabulated (*see* Table 3, part B; data in rows entitled "Accuracy M" for the data reported in the rows entitled "Manual", and data in rows entitled "Accuracy A" for the data reported in the rows entitled "Automated A"). Typically, the data obtained from the 40 mm disks are approximately 50% more accurate. The "Automated A" data from the 35 mm disks are consistently less accurate and biased low when the 40 mm disk calibration is used. When the XRF-calibration SRM were re-prepared as 35 mm diameter disks, the XRF analysis recalibrated using these smaller disks and the test repeated, the improved accuracy became evident (*see* Table 3, part B, reported as "Accuracy"). For elements not approaching their determination limit by XRF (e.g., those not marked by superscript "3" in Table 3, part B), the accuracy ranges from ±1.67% to ±0.69% and averages ±1.0%. This is more accurate than the results determined using the 40 mm calibration disks and, thus, the 35 mm diameter disk results are used.

Jobs of samples are grouped into batches for sample preparation in the XRF laboratory. Quality-control samples are inserted into the batches. In each batch, there is a sample-preparation control sample (*see* Table 3, part C, BAS–55—a basalt), an accuracy control sample (a SRM which is chemically similar to the majority of the samples in the batch; e.g., *see* Table 3, part C, MRG–1—a gabbro) and a selection of in-house reference materials (MRB-series samples). BAS–55 and MRG–1 were selected as control samples because these samples are compositionally similar to more than 60% of the samples that are submitted to the XRF laboratory. The long term (14 month) precision data for BAS–55 and MRG–1, covering the period of time in which the fluxer has been in operation, are listed in Table 3 (part C). Relative standard deviations average ±2.81% for these samples, indicating that the precision of the Geoscience Laboratories' XRF laboratory is excellent.

Damage to Crucibles due to S or Cu Contents of Samples

To withstand the high heat required for disk production, crucibles must be made of a 95% platinum and 5% gold alloy. Compounds other than Pt-Au cannot be used as they have either a melting point that is too low, or are even more expensive, or add major element contamination to the sample, or become brittle with minimal use or are readily attacked by the flux. However, samples that are high in sulphur or copper react with the platinum-gold alloy and damage the crucibles and moulds. In the worse case (which has occurred when beads were made manually at the Ontario Geological Survey), the bottom dissolves out of the crucible and the molten sample flows over the burner. More typically, the Cu- or S-rich sample will etch or combine with the inside margins of the crucibles. When this happens, the glassy shards of the sample must be extracted. As much as possible is removed by scraping the glass away with a pointer. Remaining material is removed by making a silica bead in the crucible. The silica is fused like a sample and small amounts of glass are removed. Experience has shown that the use of well-maintained and undamaged platinum-ware results in a melt that pours better, does not wet the sides of the crucible as much and cools to form a disk with a flat, unpitted surface, thus ensuring better analytical results.

Table 4. Comparison of manual and automated methods of producing XRF glass disks in terms of efficiency and productivity.

Efficiency and Productivity	Manual Method	Automated LECO FX200
base productivity	2 beads/30 min	6 beads/20 min
daily production	24 beads/day	96 beads/day
% analyst attendance time/day	100% (6 hrs)	40% (2.5 hrs)
efficiency comparison	6.5 days/160 beads	1 day/160 beads
possible production in 1 yr (230 d/yr)	3840 beads	368 000 beads
# people required by OGS/year for this task	1 full-time	20% (other 80% now spent running XRF)

Table 5. Comparison of manual and automated methods of producing XRF glass disks in terms of operating costs.

Operating Costs	Manual Method	Automated Method	Benefit
Platinum-Ware			
Moulds (wt)	52 g	32 g	Smaller mould
Crucibles (wt)	45 g	37 g	Smaller mould
Total	97 g	69 g	Cost saving
Cost (Pt alone)	$2 283.09	$1 624.05	Cost saving
Cost (per year)	$27 397.08	$18 488.60	Cost saving
Chemicals			
Lithium tetraborate	$3.84	$1.05	Cost saving
(per year)	$11 520	$9 360	Cost saving
Oxygen (gas)	$0	$1.27	Additional Cost
(per year)	$0	$3 810	Additional Cost

PRODUCTIVITY AND VERSATILITY: ADVANTAGES OF AUTOMATION

Automatic sample preparation allows the Geoscience Laboratories greater safety, efficiency, reproducibility, increased productivity and cost effectiveness in the preparation of XRF samples (Table 4). Options are easily selectable and provide operational flexibility, save time and eliminate unnecessary procedures. Specifically, the fluxer can automatically prepare 6 samples in a batch and can produce 96 glass disks in a full working day. A batch is prepared in 23 minutes, compared to 30 to 35 minutes when prepared manually. Typically, the operator can prepare samples, operate the XRF or complete other duties while the fluxer is operating in a relatively unattended fashion.

Use of the fluxer allowed the Geoscience Laboratories Section to quadruple the efficiency by which samples are prepared for XRF analyses and has accounted for significant savings in redeployment of time. Since smaller sample sizes and smaller crucibles, moulds and reagent volumes are used, an annual savings in terms of chemicals and platinum-ware has been realized (Table 5).

CONCLUSIONS

1. Sample preparation for X-ray fluorescence can be automated in a cost- and time-efficient manner.
2. The quality of the glass disks (XRF samples) prepared by the fluxer for XRF analyses is consistently homogeneous and defect free. The disks are reproducible in quality and safely produced with little operator attention. XRF analysts are now able to devote more time to other operational activities in the laboratory.
3. Automatic sample preparation allows the Geoscience Laboratories Section greater time, cost efficiency and reproducibility in the preparation of XRF samples. Thus the cost of the instrument was recovered in the first year of operation.

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49. Project Unit 91–16. Quality Control Measures for Multielemental Analysis of Base Metals (Ba, Cd, Co, Cr, Cu, Fe, Li, Mn, Ni, Pb and Zn) by Flame Atomic Absorption Analysis

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INTRODUCTION

Determination of the base metals for the Geoscience Laboratories Section's client group has played an important role in both mapping programs and lithogeochemical studies. Although much of the analytical work is now performed by the inductively coupled plasma optical emission spectroscopy method (ICP-OES), the flame atomic absorption method is routinely used for the determination of base metal (Co, Cu, Fe, Mn, Ni and Zn) analytes, determinations not performed by inductively coupled plasma optical emission spectroscopy such as Cd, Li and Pb and characterization of samples for other, more difficult analytes such as Ba and Cr.

How can geologists, prospectors and our other clients be sure that the data they receive from the Geoscience Laboratories Section are both precise and accurate and measured at levels appropriate to the geological materials of interest? Within the Chemistry Subsection of the Geoscience Laboratories Section, many steps are taken to ensure the quality and integrity of the analytical data which is released to our clients. Quality control is an ongoing process which commences when the sample is collected, continues through to the preparation and data-reporting stage and continues further along to include the correct interpretation of the data (bearing in mind the sensitivity of the method). This paper will focus on the quality control methods which are applied to the samples when they enter the Chemistry Subsection. These methods include the following:

1. manual methods, such as an analyst rolling a sample to ensure homogeneity
2. visual inspection to see if sample dissolution is complete
3. established procedures to ensure peak performance of the flame atomic absorption spectrophotometer
4. analysis of control standards and blanks
5. statistical calculations and preparation of control charts.

Flame atomic absorption analysis is primarily a method for solutions and, as such, has a great advantage over samples which are analyzed in a solid form. In solid samples, inhomogeneity due to segregation of mineral grains or inadequate sampling can lead to erroneous results. Solutions, on the other hand, are either homogeneous or can be made homogeneous and will yield more representative results provided, of course, that decomposition and dissolution of the sample is complete. The solution can then be presented to the flame atomic absorption spectrophotometer for analysis.

After decomposition and dissolution, the analyte solution is aspirated into the flame in the form of a fine mist via the nebulizer-burner. Once in the flame, desolvation, dissociation and atomization occurs. The flame stoichiometry must be optimized to allow a maximum of analyte atoms to interact with the beam generated by a hollow cathode lamp and to minimize ionization of the analyte atoms. The beam, which is specific to the analyte of interest, is weakened by absorption by the analyte atoms in the flame, and there is, therefore, a commensurate decrease in intensity which is measured by a photomultiplier tube. This percentage of absorption can be related to the concentration of the analyte and is the basis behind flame atomic absorption spectroscopy (Slavin 1978).

QUALITY CONTROL DURING SAMPLE PREPARATION

Prior to performing analyses, sampling techniques and sample preparation to convert geological samples into powders are critical. Should these steps be compromised, a continuation of the analysis would be pointless as the results would not be representative. Quality control measures used during sampling, crushing and grinding are presented in the Geoscience Laboratories Section's manual of methods (OGS 1990) and will not be dealt with here.

Once a powder is available, the analyst must use care and visual inspections throughout the sample's preparation to ensure that the analytical data are correct. The following steps are identified:

1. Weighing of the Sample

An analyst begins by weighing 0.500 g of sample as accurately as possible so that a final dilution factor of 50 is obtained.

Prior to weighing, the analyst will ensure that the powder is well blended by rolling the sample to prevent mineral segregation from occurring. Certain minerals, such as chromite, tend to gravitate to the bottom of a sample jar with time, whereas lighter minerals, such as the micas, tend to float to the surface. The samples are then transferred to PTFE (teflon) beakers for decomposition with an acid mixture. Certain minerals, especially sulphide minerals, tend to possess an electrostatic charge which causes them to plate beaker walls. To ensure that all of the sample will be in contact with the acid mixture, static is removed from the beakers with an antistatic gun. Should this prove to be insufficient, the analyst will carefully wash the sample down with a small amount of distilled water.

2. Decomposing the Sample

Once the samples have been weighed, a 15 mL aliquot of an acid mixture is added to each sample which is then gently swirled to ensure complete wetting with acid. The samples are placed on a hot plate at a preset temperature so that they may evaporate to dryness. Periodically, the analyst will swirl the contents and gently tap down the acid droplets which condense on the beaker's walls. The purpose of this step is twofold: the swirling and tapping maximizes contact between the acid and the sample and the analyst is able to observe any unusual behaviour or problems which may be occurring during the decomposition.

On occasion, the preset temperature settings on the hot plates are verified. It has been observed that if the hotplate temperature is too low or if it should fluctuate drastically, reproducibility problems will be encountered. These problems may manifest themselves both in low values for our in-house reference standards and in poor precision between duplicates. Should this occur, the analysis is repeated.

Once the samples have evaporated to dryness, there is another addition of acid followed by an addition of water to dissolve the salts. Once more, the observational powers of the analyst play a vital role in the quality of the analysis. The analyst examines and notes if there are undissolved particulates present while bringing the samples up to their final volume. The presence of particulates may indicate that incomplete dissolution of some elements has taken place. For example, if chromium is required and there are dark granular particulates present, then these may be undissolved chromites. A fine white precipitate could be barium sulphate or lead chloride. Should any of these precipitates be present, then an alternate decomposition method, such as, for example, fusion, is used.

QUALITY CONTROL DURING ANALYSIS

Prior to analyzing any sample by flame atomic absorption spectroscopy, it is imporant that the instrument be optimized to analyze for a particular analyte. The selection of the correct wavelength and slit width, along with the optimization of the burner position and oxidant-to-fuel ratio will impact on the sensitivity and performance of the instrument. Once optimized, the instrument is calibrated from a series of standards prepared from a commercial standard. The instrument used for routine analysis of base metals is a Varian AA775™ which incorporates the Varian rational algorithm. This algorithm calculates the calibration curve and, should it not be linear, will prompt the analyst to verify the standards used and prepare new ones if necessary.

During the analysis, the analyst constantly monitors the instrument to make sure that there is no blockage within the nebulizer or the burner—all being factors which can impede instrument performance. Once the analysis is complete, the results are carefully entered into the laboratory information management system (LIMS) where control charts can be called up to see whether or not the results for the control-standard values are precise and agree with expected values.

THE USE OF REFERENCE MATERIALS, BLANKS AND DUPLICATES FOR QUALITY CONTROL

To ensure that sample decomposition is complete, that no errors have occurred and that no contamination has taken place, in-house control standards (the MRB series) and blanks are used. The values of the in-house standards obtained during an analytical run are compared to a data base of in-house standard values. These values are called up from the LIMS in the form of control charts, where actual analytical values are compared to the average values and to see whether or not the actual values fall within the 95% (2σ) confidence range. The aim is to maintain precision and accuracy. Should a deviation occur, the analyst would suspect that a problem has occured during the sample decomposition and/or the analysis. The controls would be read once more to rule out the possibility of poor instrument optimization. Should this not solve the problem, then a sample decompositon problem is suspected. Once the problem has been identified, the necessary corrective action would be taken. Periodically, as a further verification of analytical technique, commercial standard-reference materials, such as those purchased from Canada Centre for Mineral and Energy Technology (CANMET) in Ottawa, are included in an analytical run.

In geoanalysis, contamination is always a concern. It is for this reason that an analytical blank is prepared along with the samples. If there is any contamination—be it either airborne or from reagents used during the decomposition—it will show up when the blank is analyzed. The value from the blank is then subtracted from the sample values. If serious contamination is present, the analysis is repeated.

For batches of samples which are submitted by geologists, duplicates are included to further verify the precision of the analysis. The number of duplicates within a batch is proportional to the number of samples in the batch. If the values of the duplicates vary by more than 5%, all possible causes are checked to find the source of the discrepancy, and action will be taken if necessary.

Table 1 contains a list of some commonly used, in-house standards along with the average value of certain elements, their standard deviation (σ) and their relative standard deviation (rsd). Relative standard deviation is calculated as follows:

$$\% \text{ rsd} = (\sigma/\text{mean}) \times 100 \qquad \text{(Taylor 1990)}$$

A typical analytical run will usually contain at least 3 in-house standards and 1 blank. Table 2 contains the determination limits and optimun range for elements determined in the Chemistry Subsection of the Geoscience Laboratories Section.

CONCLUSION

As can be seen from Table 1, some elements such as Ba and Cr have a larger standard deviation and a greater %rsd than other elements. These elements are problematic, and research to improve the detection limit, the standard deviation and the dispersion from a central value either through new decomposition techniques or through the adoption of alternate instrumental techniques are underway. Research in automated sample preparation which would minimize variability due to human intervention and perhaps overcome some decomposition shortfalls is also in progress. Although flame atomic absorption spectrophotometry (a sequential method of analysis) may not be as new a technique as inductively coupled plasma optical emission spectroscopy (a simultaneous method of analysis), it has, nonetheless, similar detection limits for many base metals and will analyze certain base metals more reliably than the latter method of analysis. Flame atomic absorption has been around for a number of years and has proven itself in the analysis of geological materials.

The production of quality, meaningful and useful data is by no means an easy task. When generating geoanalytical data, the following should be considered:

1. No instrumental technique will analyze all elements. The choice of technique will depend on the elements required for analysis, the precision and accuracy required, and the detection limits needed by the client;
2. No step, from sampling through analysis and finally to data reduction, can be compromised without the quality of the analytical data being affected;
3. The use of control standards, blanks and duplicates as a system of checks and balances is important and should not be ignored.

Table 1. The average values, the standard deviations and the relative standard deviations for various elements analyzed by FAAS in the Geoscience Laboratories Section in-house reference materials.

MRB-7

Elements	Ba	Co	Cr	Cu	Fe	Li	Mn	Ni	Pb	Zn
Mean	68	46	377	81	8	18	1278	206	n/a	93
Standard Deviation	21	3	34	2	0.57	1	58	7	n/a	5
% rsd	18	7	9	2	7.13	6	5	3	n/a	5

MRB-8

Elements	Ba	Co	Cr	Cu	Fe	Li	Mn	Ni	Pb	Zn
Mean	555	n/a	162	5	1.11	11	123	6	n/a	19
Standard Deviation	49	n/a	34	1	0.12	1	10	1	n/a	2
% rsd	9	n/a	21	20	10.81	9	8	17	n/a	11

MRB-9

Elements	Ba	Co	Cr	Cu	Fe	Li	Mn	Ni	Pb	Zn
Mean	1036	n/a	123	7	1.25	16	191	8	10	31
Standard Deviation	57	n/a	23	1	0.1	1	15	1	2	2
% rsd	6	n/a	19	14	8	6	8	13	20	6

MRB-29 (formerly BAS-55)

Elements	Ba	Co	Cr	Cu	Fe	Li	Mn	Ni	Pb	Zn
Mean	308	45	249	145	8.91	11	1334	100	n/a	116
Standard Deviation	23	3	15	8	0.48	2	68	6	n/a	4
% rsd	7	7	6	6	5.39	18	5	6	n/a	3

Note: all values are reported as ppm except for Fe values which are reported as percentages (%). The high % rsd's in the shaded boxes reflect the low concentration of analytes.

Table 2. Determination limits and optimum range for elements determined in the Chemistry Subsection, Geoscience Laboratories Section.

Element	**Determination Limit** (ppm)	**Optimum Range** (ppm)
Ba	10	10–1000
Cd	2	2–200
Co	5	5–200
Cr	10	10–500
Cu	5	5–200
Fe	5	5–500
Li	3	3–200
Mn	5	5–200
Ni	5	5–200
Pb	10	10–200
Zn	10	5–200

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Northern Ontario Development Agreement

50. Project Unit 91–20. Geology of Foleyet and Ivanhoe Townships, Northern Swayze Greenstone Belt

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INTRODUCTION

A three year project to update the geological mapping database in the northern Swayze greenstone belt was initiated by mapping of Foleyet and Ivanhoe Townships during the 1991 field season. The map area (*see* Figure 1), situated between latitudes 48°03'N and 48°19'N and longitudes 83°24'W and 83°36'W, was mapped at a scale of 1:15 840. The town of Foleyet is located in the southeastern part of Foleyet Township about 100 km west of Timmins. Access to the map area is from Highway 101 and associated secondary roads. Funding is provided by the four-year Northern Ontario Development Agreement, a subsidiary agreement to the Canada-Ontario Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

Outcrop density is generally low because of extensive glacial till and outwash sand cover. As a result, geological interpretation is also dependent on data from airborne magnetic and electromagnetic surveys (Ontario Department of Mines-Geological Survey of Canada 1963a–d; Ontario Geological Survey 1990a–f), information derived from assessment files (Resident Geologist's Office, Timmins) and diamond drill core stored at the Timmins Drill Core Library. Rocks of the Shawmere anorthosite complex in northwestern Foleyet Township were previously mapped at a scale of 1:15 840 (Riccio 1981a, 1981b) and were not included in the current mapping project.

MINERAL EXPLORATION

The following information is derived from the assessment files of the Resident Geologist's Office, Ministry of Northern Development and Mines, Timmins. Recorded past exploration activity has been mainly focused on diamond drill indicated, base metal sulphide occurrences and was restricted to southeastern Foleyet and northeastern Ivanhoe Townships. This

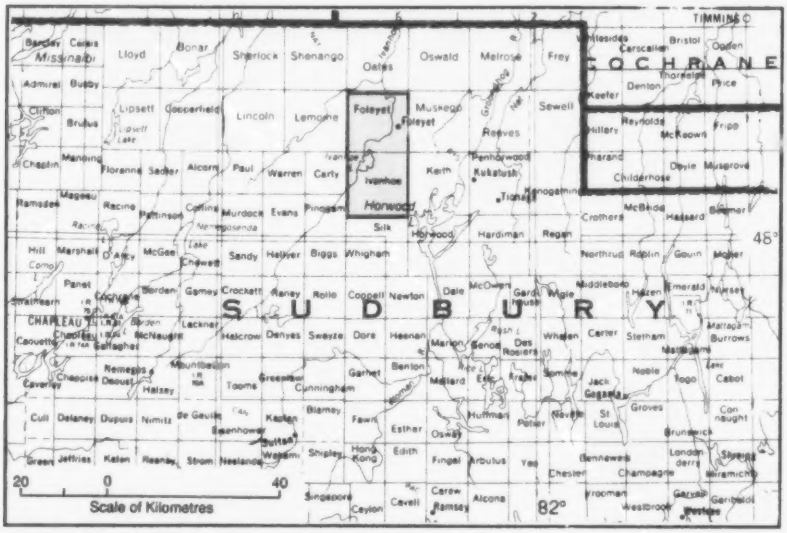
TIMMINS
COCHRANE
SUDBURY
CHAPLEAU
Foleyet
Ivanhoe
Horwood
Oates
Oswald
Melrose
Frey
Muskego
Reeves
Sewell
Keith
Penhorwood
Kukatush
Tionaga
Silk
Hardiman
Regan
Lincoln
Lemoine
Carty
Warren
Paul
Pinogami
Murdock
Evans
Sherlock
Shenango
Lloyd
Bonar
Lipsett
Copperfield
Missinaibi
Whitesides
Carscallen
Bristol
Ogden
Denton
Thorneloe
Price
Keefer
Hillary
Reynolds
McKeown
Fripp
Childerhose
Doyle
Musgrove
Crothers
McBride
Hassard
Northrup
Roblin
Gouin
Sandy
Biggs
Whigham
Newton
Dale
Swayze
Dore
Heenan
Marion
Benton
Garnet
Cunningham
Esther
Edith
Singapore
Ceylon
Cavell
Carew
Ramsay
Alcona
48°
82°
20
0
40
Scale of Kilometres

Figure 1. Location of Foleyet and Ivanhoe townships, scale 1:1 584 000.

This project is funded under the Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Canada-Ontario Economic and Regional Development Agreement.

work began in 1964 and continues to the present time. In 1964 and 1965, Keevil Mining Group Limited conducted ground electromagnetic and magnetic surveys, geological mapping and diamond drilled 13 holes totalling 6051 feet (1845 m) in southeastern Foleyet and northeastern Ivanhoe Townships. Subeconomic massive to disseminated sulphides comprising pyrite, pyrrhotite and minor sphalerite and chalcopyrite were intersected in several holes. The best assay value was 0.35% Zn and 0.07% Cu over 11.5 feet (3.5 m). In 1964 and 1966, International Nickel Company of Canada Limited diamond drilled 7 holes totalling 1052 feet (321 m) in southeastern Foleyet Township. Minor sulphides were noted but no assay results were filed for assessment. From 1970 to 1972, Noranda Exploration Company Limited conducted ground electromagnetic and magnetic surveys and diamond drilled 2 holes totalling 735 feet (224 m) in southern Foleyet Township. Reported assays indicated only trace base metal and precious metal values. From 1980 to 1983, Hudbay Mining Limited conducted airborne and ground electromagnetic and magnetic surveys and diamond drilled 6 holes totalling 629.8 m in southeastern Foleyet and northeastern Ivanhoe Townships. Disseminated to massive sulphides including pyrite, pyrrhotite and minor sphalerite and chalcopyrite occur in several of holes with the best reported assay being 0.6% Zn over 0.9 m.

A total of 85 claims are in good standing in the map area to the end of 1991. Noranda Exploration Limited holds a total of 42 claims in 3 separate groups in southeastern Foleyet Township and 1 group in southeastern Ivanhoe Township. Falconbridge Limited holds 35 claims in northeastern Ivanhoe Township in a group which extends to the east into Keith township. Cominco Limited has 10 claims in southeastern Foleyet Township in 2 groups, one of which extends to the east into Muskego Township. C.M. Kean holds 2 adjacent claims in southeastern Foleyet Township.

GENERAL GEOLOGY

A 1:63 360 scale geological map by Harding (1937) included all of Ivanhoe and the southern ½ of Foleyet Township. A regional scale mapping project at a scale of 1:250 000 by Thurston et al. (1977) included all of the map area. Riccio (1981a, 1981b) mapped the northwestern part of Foleyet Township at a scale of 1:15 840. The map area is also included in a 1:100 000 scale map by Percival (1981).

With the exception of Proterozoic diabase dikes all rocks are of Archean age. The oldest rocks appear to be the paragneisses and amphibolites metamorphosed to granulite facies rank of the Kapuskasing structural zone in the western part of the map area. They are part of a sedimentary-volcanic succession intruded by the Shawmere anorthosite complex which is in turn intruded by orthogneiss dated at 2765 Ma (Percival 1990). East of the Kapuskasing structural zone, the rocks of the Swayze greenstone belt and associated intrusions have the presumably younger ages of 2715–2700 Ma typical of the "Keewatin-type" supracrustal rocks of the southern Abitibi subprovince (Corfu et al. 1991). These younger supracrustal rocks are metamorphosed to greenschist and amphibolite facies rank. Two lithologically distinct supracrustal assemblages are recognized in the Swazye greenstone belt in the map area. They are called the Muskego-Reeves assemblage (MRA) and the Horwood Lake assemblage (HLA) (*see* Figure 2) after the subdivisions established for the Abitibi Subprovince by Jackson and Fyon (in press).

Muskego-Reeves Assemblage (MRA)

The MRA is a very diverse lithological succession comprising both volcanic and sedimentary units. The units trend easterly and young to the south. Extrusive rocks are mainly mafic flows with subordinate units of ultramafic flows and felsic to intermediate flows and pyroclastic rocks. Mafic flows are pillowed to massive and locally amygdaloidal. Supercooling textures are common and include varioles and massive mafic flows with spinifex-like acicular mafic and plagioclase crystals in a fine-grained groundmass. Ultramafic flows are talcose and are typically polyhedral jointed to rarely spinifex-textured. Felsic volcanic rocks are feldspar- and/or quartz-phyric. They occur as extensively brecciated flows and fragmental units which include both monolithic pyroclastic deposits and heterolithic debris flows. Sedimentary units comprise mainly thickly- to thinly-bedded wackes and feldspar-phyric tuffaceous wackes. Thickly-bedded conglomerates contain poorly-sorted, subangular, heterolithic volcanic and subvolcanic intrusive clasts. Where exposed in outcrop along the Ivanhoe River in Foleyet Township, they are extremely thickly bedded and normally graded with rare massive sulphide clasts consisting of pyrrhotite and minor chalcopyrite. Here the conglomerates are intimately interbedded with ultramafic flows and graphitic mudstones. Thin- to thickly-bedded magnetite-chert ironstone interbedded with ultramafic and mafic volcanics was observed in core and reported in diamond drill logs in the northern part of the MRA in southeastern Foleyet Township (*see* Figure 2). An aeromagnetic anomaly is associated with this unit and extends from south of the Canadian National Railway rail line at the Muskego-Foleyet Township boundary to just east of Highway 101 (Ontario Geological Survey 1990a–f).

Horwood Lake Assemblage (HLA)

The southern part of the Swayze greenstone belt in the map area is underlain by the HLA. The assemblage comprises monatonous mafic volcanic flows which differ from those of the MRA principally in their lack of intercalations of ultramafic volcanic rocks, felsic volcanic rocks or sedimentary rocks and the presence of extensive gabbroic bodies (*see* Figure 2). The boundary between the MRA and the HLA is the Muskego River fault which also delineates an abrupt transistion from greenschist facies rocks to the north into amphibolite facies rocks to the south. Mafic volcanic rocks of the HLA are amphibloitized and commonly garnitiferous. Pillow selvages,

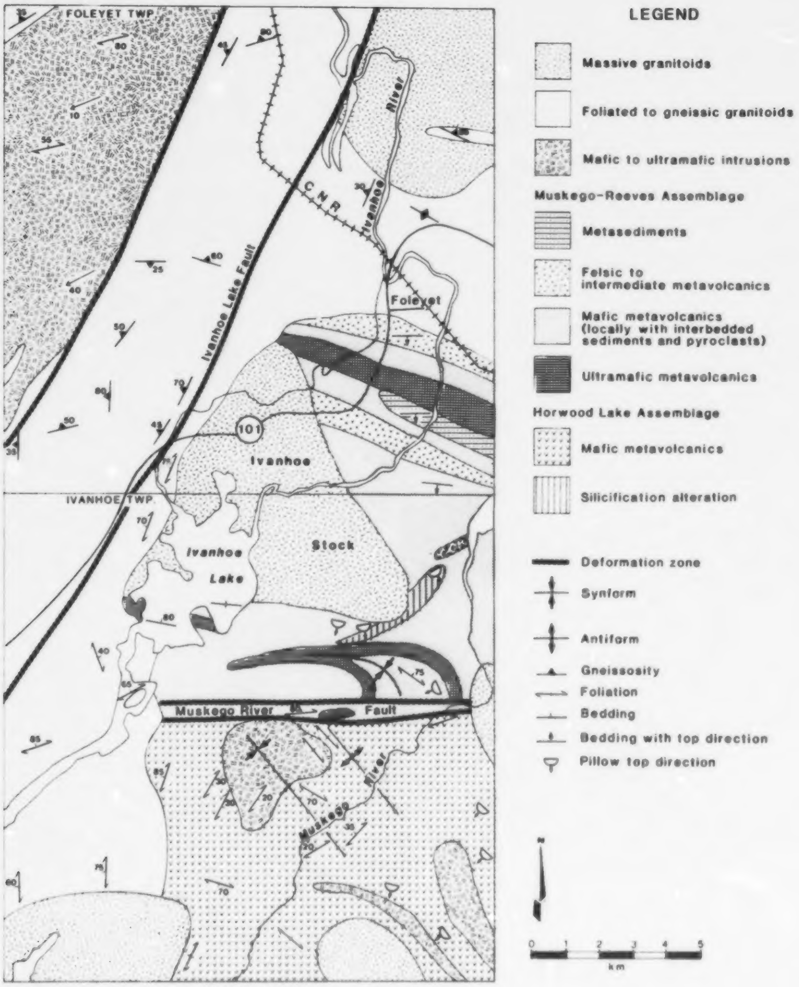
FOLEYET TWP.
IVANHOE TWP.
Ivanhoe Lake Fault
C.N.R.
Ivanhoe River
Foleyet
101
Ivanhoe
Stock
Ivanhoe Lake
Muskego River
Fault
Muskego River
LEGEND
Massive granitoids
Foliated to gneissic granitoids
Mafic to ultramafic intrusions
Muskego-Reeves Assemblage
Metasediments
Felsic to intermediate metavolcanics
Mafic metavolcanics (locally with interbedded sediments and pyroclasts)
Ultramafic metavolcanics
Horwood Lake Assemblage
Mafic metavolcanics
Silicification alteration
Deformation zone
Synform
Antiform
Gneissosity
Foliation
Bedding
Bedding with top direction
Pillow top direction
N
0
1
2
3
4
5
km

Figure 2. General geology of Foleyet and Ivanhoe townships.

varioles and amygdules are locally evident. Where preserved, pillow tops indicate consistent facing to the southwest. Near the south-central margin of the map area the garnetiferous, amphibolitized mafic flows contain rounded epidote-rich pods averaging 10-20 cm, which can comprise up to 50% of the rock.

Synvolcanic Intrusions

Lenticular bodies of mainly gabbro, with minor leucogabbro, melagabbro and pyroxenite occur within both the MRA and HLA supracrustal sequences. Locally cross-cutting contacts indicate that at least some of these bodies are intrusions. However the compositional and texturaly similarity with the volcanic rocks strongly suggest they are synvolcanic and some may in fact be large massive flows. As mentioned previously gabbroic bodies are more extensive in the HLA. These are sill-like in their relationship with the associated mafic volcanic rocks. The map pattern of the irregular-shaped gabbro body in the central part of Ivanhoe Township (*see* Figure 2) might normally suggest a plug-like intrusion. However, it also is a sill-like body which is gently-dipping to the east and has been folded in the nose of a shallow southeast-plunging synform.

Pretectonic Granitic Intrusions

Much of Foleyet Township and the west part of Ivanhoe Township are underlain by gneissic-textured to strongly foliated granitic intrusions. West of the Ivanhoe Lake fault (*see* Figure 2) the gneisses of the Kapuskasing structural zone are compositionally variable consisting mainly of tonalite and granodiorite. The tonalite gneiss commonly contains abundant amphibolite xenoliths and in the northern part of Foleyet Township amphibolite gneiss is more abundant than tonalite gneiss. Minor quartz undersatuarated phases comprising diorite and monzonite gneiss occur adjacent to the Shawmere anorthosite complex in southwestern Foleyet Township.

East of the Ivanhoe Lake fault, the pretectonic intrusions surround the Swazye greenstone belt to the north and west. In the northeastern part of Foleyet Township the gneises are predominantly tonalites with inclusions of paragneiss and amphibolite. In Ivanhoe Township, the early granitic intrusions are less deformed ranging from moderately to weakly foliated. Compositions are highly variable and include tonalite, granodiorite, granite and a narrow body of alkalic affinity extending from along the Ivanhoe Lake fault in southern Foleyet Township about 10 km to the southeast, into west-central Ivanhoe Township. Alkalic phases include monzonite, syenite, syenodiorite and diorite. Abundant xenoliths of hornblende-biotite gabbro, hornblendite and pyroxenite occur locally within this alkalic intrusion.

Post-tectonic Granitic Intrusions

Massive, unfoliated granitic intrusions are restricted to east of the Ivanhoe Lake fault. These intrusions tend to be more potassic than the pretectonic granitoids. Compositions are predominantly granite and granodiorite with or without tabular alkali feldspar phenocrysts. Both of the intrusions in the northeast and southwest corners of the map area are granites extensively invaded by pegmatites with graphic-textured intergrowths of perthite and quartz. The Ivanhoe Lake stock is predominantly granodiorite in the west and quartz monzodiorite in the east. The stock has a zircon U-Pb date of 2680 +3/-2 Ma supporting a late, post-tectonic, crystallization age (Percival and Krogh 1983).

STRUCTURAL GEOLOGY

Kapuskasing Structural Zone

Throughout the Kapuskasing structural zone gneissosities generally dip moderately to the northwest. Mineral lineations and small scale folds in gneissosity have shallow plunges to the southwest. Two northwest-trending late faults occur in the zone. The western fault lies along the eastern margin of the Shawmere anorthosite complex and was previously recognized by Riccio (1981a, 1981b). It is characterized by numerous "veinlets" of black, aphanitic pseudotachylite and mylonite. These cataclastic zones range up to several centimetres thick, and are extremely variable in orientation cross-cutting the gneissosity. The eastern fault has been identified as the Ivanhoe Lake fault and is considered to be the boundary between the Kapuskasing structural zone and the Abitibi Subprovince (Percival 1990). In the map area the Ivanhoe Lake fault is characterized by augen-textured monzonite gneiss exposed along the old channel of the Ivanhoe River north of the Highway 101. The monzonite gneiss has shallow west-plunging stretching lineations and gently southeast plunging folds in the gneissosity with assymetry indicating southeast-directed thrusting along the fault zone.

North Swayze Structural Zone

East of the Kapuskasing zone the gneissosities are more variable in trend and are generally parallel to the S_1 foliations in the adjacent supracrustal rocks of the Swayze greenstone belt suggesting a cogenetic structural evolution. There is evidence for at least three deformational episodes in the supracrustal rocks. An S_1 foliation or cleavage is evident in most supracrustal outcrops as a flattening fabric which is generally subparallel to stratigraphy. S_2 is evident as variably developed steeply-dipping cleavage crenulating the S_1 fabric or axial planar to upright F_2 folds in the S_1 fabric. D_3 has a relatively minor expression in the map area as shallow dipping crenulations and kink bands cross-cutting the S_1 and S_2 fabric.

Evidence for F_1 folds are scarce as a result of the general lack of outcrop and top indicators. A fold in an ultramafic volcanic unit (partially inferred from aeromagnetic data) appears to represent an F_1 fold in the southern part of the MRA (*see* Figure 2). S_1 foliations are quite variable in orientation in the HLA as a result of F_2 folding. In many places the S_1 foliation has much shallower dips in the amphibolites of the HLA in contrast to the consistently steep dips of S_1 foliations in the greenschist facies rocks of the MRA. F_2 megascopic folds reorient S_1 foliations in an upright synform-antiform pair with northwest-trending axial traces in the northern part of the HLA. Associated F_2 minor fold axes and L_2 lineations change in orientation from shallow southeast plunges north of the Muskego River to shallow northwest plunges south of the river.

The Muskego River fault is a broad east-trending deformation zone comprising variably schistose and carbonatized rocks. The fault separates the MRA and HLA terranes. South side up displacement is indicated by the transistion from greenschist to amphibolite facies rank across the fault. However, dextral strike-slip displacement is also suggested by the reorientation and truncation of the limbs of the F_1 fold in the southern margin of the MRA (*see* Figure 2).

ECONOMIC GEOLOGY

The map area is considered by the author to have good potential for volcanogenic massive sulphides within the MRA in the northern part of the Swayze greenstone belt. This potential is indicated by several diamond drill intersection of subeconomic stratabound massive sulphides and widespread hydrothermal alteration including silification and chloritoid-bearing volcanic rocks. An extensive silification zone occurs in mafic volcanic rocks in northeastern Ivanhoe Township cut by the southeastern margin of the Ivanhoe Lake stock (*see* Figure 2). The silicification is controlled by the original porosity of the volcanics. This is seen in the extensive alteration of highly amygdaloidal flows and hyaloclastites closely associated with relatively unaltered non-amygdaloidal and unbrecciated pillowed and massive flows. Chloritoid porphyroblasts occur in carbonatized mafic volcanic rocks underlying a subeconomic stratabound masssive sulphide horizon in a diamond drill hole in southeastern Foleyet Township (Hole F82-5, Timmins Assessment file # T-2430; Timmins Drill Core Library # TI0497) and was also observed in outcrops of carbonatized felsic volcanic rocks along the Ivanhoe River 1.4 km along strike, east of the drill hole collar. It is worthy of note that similar-appearing silicification zones and chloritoid-bearing altered volcanic rocks are associated with a number of Archean volcanogenic massive sulphide deposits (eg. Gibson et al. 1983; Franklin et al. 1975).

Gold potential may exist associated with easterly-trending carbonatized shear zones such as the Muskego River fault. The Keith-Penhorwood deformation zone, along strike with the Muskego River fault to the east hosts gold mineralization at the Joburke Mine and a number of other gold prospects (Siragusa 1990).

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51. Project 91–12. Geology and Mineral Potential of Moss Township, Shebandowan Greenstone Belt, District of Thunder Bay, Ontario

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INTRODUCTION

This is the first year of a three year mapping project of the west-central Shebandowan greenstone belt, an area of Archean Supracrustal rocks which form part of the Wawa Subprovince in northwestern Ontario. This project is jointly funded by the four-year Northern Ontario Development Agreement, a subsidary agreement to the Canada–Ontario Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario. The purpose of the project is to update and expand the geological data base and to evaluate mineralization potential.

The map area (Figure 1) consists of all of Moss Township, covering approximately 210 km^2, and is bounded by longitudes 90°52'23"W and 90°39'29"W and latitudes 48°29'60"N and 48°36'46"N.

Access to the map area is by Highway 11 west from Thunder Bay to the village of Kashabowie and from there several gravel roads lead into the map area. Alternate means of access would be by float or ski-equipped aircraft to Moss, Fountain and Burchell lakes.

Preliminary findings are summarized in this report and a preliminary map based on this survey will be released early in 1992.

MINERAL EXPLORATION HISTORY

The map area contains one past-producing gold mine which operated intermittently from 1875–1936, under the names of Jackfish, Huronian, Moss, Kerry and Ardeen mines (Harris 1970). The earliest exploration activity, which led to the discovery of the mine, dates back to 1871. At that time a sample

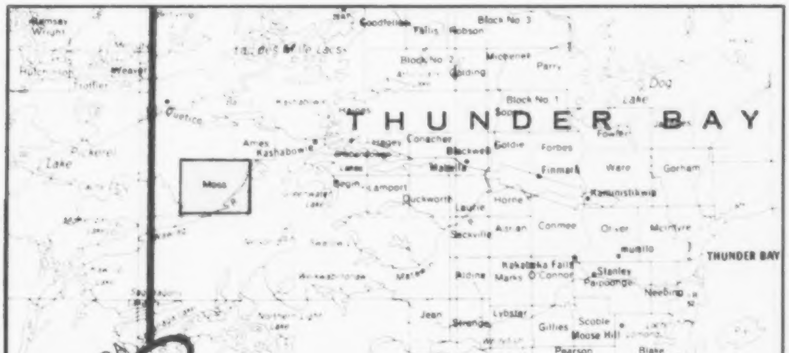
THUNDER BAY
Moss
Kashabowie
Ames
Quetico
Goodfellow
Block No 3
Block No 2
Block No 1
Robson
Fallis
Michener
Parry
Golding
Dog Lake
Conacher
Blackwell
Goldie
Forbes
Fowler
Finmark
Ware
Gorham
Kaministikwia
Lamport
Begin
Duckworth
Laurie
Horne
Aldina
Conmee
Oliver
McIntyre
Sackville
Murillo
Kakabeka Falls
Marks
O'Connor
Stanley
Paipoonge
Neebing
Jean
Strange
Lybster
Gillies
Scoble
Moose Hill
Pearson
Blake
Hardwick
Fraleigh
Lismore
Arrow
Robbins
Hartington
Devon
Pardee
Crooks
Mountain Lake
Pigeon River
Pickerel Lake
Northern Light Lake
CANADA
U.S.A.
LAKE SUPERIOR
48°
90°
20
0
40
Scale of Kilometres

Figure 1. Location map of the study area, scale 1:1 584 000

CANADA ONTARIO
Northern Ontario Development Agreement
Entente de développement du nord de l'Ontario
Minerals • Minéraux

This project is funded under the Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Canada-Ontario Economic and Regional Development Agreement.

of auriferous quartz vein was collected by trappers J. Baptiste and M. Douchette. Shortly after, the area was explored by pits and trenches and one-ton sample was tested, which yielded $36.20 in gold (gold at $20.67 per ounce) and $12.98 silver (Harris 1970). From 1932 to 1936 and in 1942 total production from the mine was 29 948 ounces of gold and 172 376 ounces silver from 143 724 tons of ore milled (Harris 1968).

In 1957 Noranda Inc. optioned the Huronian Mine property and carried out geological and geophysical surveys. Conductive zones were drilled. These conductive zones were found to be caused by graphitic schists containing pyrite and pyrrhotite (Harris 1970, Geological Data Inventory Folio (GDIF), Resident Geologist's Office, Thunder Bay).

A gold prospect north of Snodgrass Lake was initially explored by The Mining Corporation of Canada Limited in 1936 when 7 trenches were dug. During 1983–1987, the Snodgrass Lake property and adjacent areas were extensively drilled by Tandem Resources Limited. Approximately 54 864 m of surface and 1524 m of underground drilling were carried out during this period (*Canadian Mines Handbook*, 1991–1992). Also 1005 m of underground opening, and 275 m of drifting was done at the 200-foot level during this period. In 1989, the property was optioned to Central Crude Limited (*Canadian Mines Handbook*, 1991–1992). Under this agreement Central Crude Limited agreed to spend 6.5 million on exploration on the property. Noranda Exploration Company Limited, the project operator, is also an indirect major shareholder of Central Crude Limited through its 50%-owned subsidiary, Hemlo Gold Mines Inc., which in turn controls 41.2% of Central Crude's issued and outstanding common shares (Lavigne et al. 1990). Approximately 5977 m of drilling was carried out during 1989–1990 by Central Crude Limited (Lavigne et al. 1990). An ore reserve of 65.5 million tons grading 0.032 ounce Au per ton is reported for the prospect (*Canadian Mines Handbook*, 1991–1992).

Several gold occurrences exist within the map area (*see* Figure 2) and they are recorded in the Resident Geologist's Office in Thunder Bay, Ontario.

PREVIOUS WORK

The present map area was originally mapped by Watson (1928) at a reconnaissance scale and later by Harris (1970) at 1 inch to ½ mile. Giblin (1964) mapped part of the eastern Moss Township at the scale of 1 inch to ¼ mile. Recently, Chorlton (1987) did mapping and detailed studies on the setting of gold mineralization in the Huronian Mine and Snodgrass Lake areas.

GENERAL GEOLOGY

All rocks, except diabase dikes, are Archean in age (Corfu and Stott 1986). The map area includes part of the western Shebandowan greenstone belt of the Wawa Subprovince and metasedimentary rocks of the Quetico Subprovince. The Shebandowan belt is an arcuate supracrustal mass which forms the northern margin of the Wawa Subprovince in northwestern Ontario. The greenstone belt is bounded to the north by the metasedimentary rocks and associated granitic intrusions of the Quetico Subprovince and to the south by a granitoid batholithic complex (Ontario Geological Survey 1991a). To the north, the contact with the Quetico metasedimentary rocks is both conformable and fault-bounded (Giblin 1964; Harris 1970; Stott 1985).

Within the study area, the Shebandowan greenstone belt is bounded to the northwest by metasedimentary rocks of the Quetico Subprovince. The northern contact of the belt with the metasedimentary rocks, where exposed, is sheared; elsewhere the contact zone is underlaid by regional topographic liner features.

The Shebandowan belt, within the study area, is chiefly comprised of mafic to felsic metavolcanic units, which have been intruded by numerous syn- to post-tectonic mafic to felsic intrusive rocks. The metavolcanic rocks of the belt, in general, form a homoclinal, north-younging sequence. The supracrustal rocks are informally subdivided into four units, namely: 1) a northern mafic to intermediate metavolcanic unit; 2) a southern mafic to intermediate metavolcanic unit; 3) a central felsic to intermediate metavolcanic unit; and 4) a central mafic to intermediate metavolcanic unit.

Narrow slivers (from a few metres up to 2 km long) of mafic metavolcanics are also found within the Quetico metasedimentary belt.

Northern Mafic to Intermediate Metavolcanic Unit

The northern mafic to intermediate metavolcanic unit (NMU) extends from the southwest for about 20 km to the northeast extremity of the Moss Township (*see* Figure 2). The thickest (3.5 km) part of this metavolcanic unit is centred immediately southwest of Moss Lake. It is bounded to the northwest by the Quetico metasedimentary belt and to the southeast by felsic to intermediate metavolcanics and Moss Lake Syenite Stock.

The NMU is chiefly comprised of massive and pillowed flows with associated pillow breccia and fragmental rocks. Pillowed flows and pillow breccia predominate in the northeast and massive flows, with subordinate pillowed lava and fragmental rocks, are dominant in southwestern part of the NMU. The fragmental rocks consist of block- to lapilli-size, subangular- to oval-shaped monolithic fragments of pillowed lava in a matrix of basaltic hyaloclastite. Intact pillows and amygdular or vesicular fragments and exotic chert clasts in the Huronian Mine and Beaver Pond areas suggest that these rocks are possibly subaqueous debris flows. The unit, in general, displays poor sorting. However, portions of this unit are noted, in places, to be well sorted, from block to ash size over 15 to

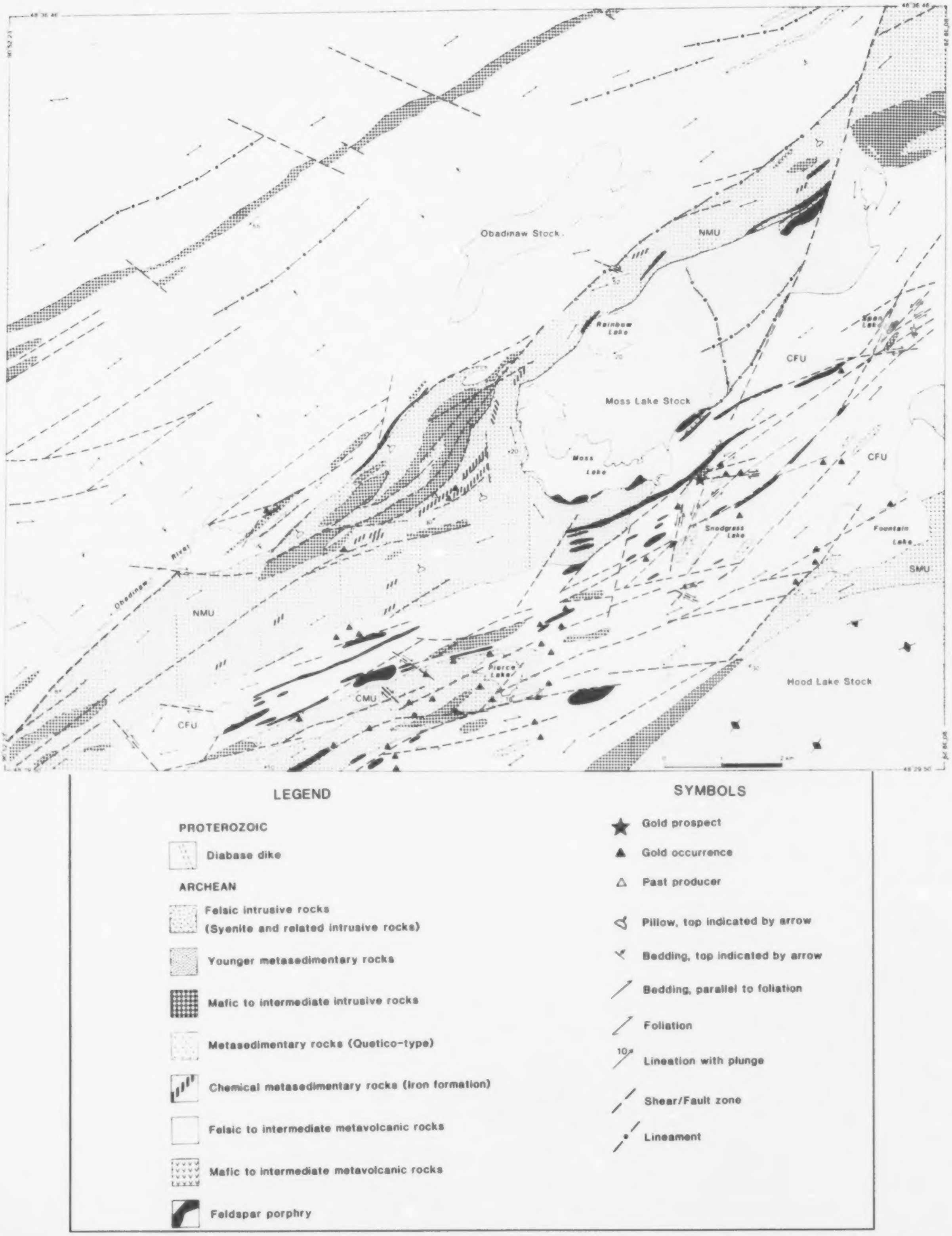
Obadinaw Stock
NMU
Rainbow Lake
CFU
Moss Lake Stock
Moss Lake
CFU
Snodgrass Lake
Fountain Lake
SMU
Obadinaw River
NMU
Pierce Lake
CMU
Hood Lake Stock
CFU
0
1
2 km
LEGEND
PROTEROZOIC
Diabase dike
ARCHEAN
Felsic intrusive rocks (Syenite and related intrusive rocks)
Younger metasedimentary rocks
Mafic to intermediate intrusive rocks
Metasedimentary rocks (Quetico-type)
Chemical metasedimentary rocks (iron formation)
Felsic to intermediate metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Feldspar porphry
SYMBOLS
Gold prospect
Gold occurrence
Past producer
Pillow, top indicated by arrow
Bedding, top indicated by arrow
Bedding, parallel to foliation
Foliation
10
Lineation with plunge
Shear/Fault zone
Lineament

Figure 2. General bedrock and structural geology of Moss Township. The distribution of gold occurrences is also shown. Abbreviations are: NMU = Northern mafic to intermediate metavolcanic unit; CMU = Central mafic to intermediate metavolcanic unit; SMU = Southern mafic to intermediate metavolcanic unit; and CFU = Central felsic to intermediate metavolcanic unit.

20 m of stratigraphic thickness and appear to mark individual smaller debris flows. Some of these fragmental rocks may possibly represent *in situ* pillow breccia set in a hyaloclastite tuff. The fragmental rocks in the Huronian Mine area are noted to overlie pillowed flows and pillow breccia. The gradation from pillow breccia to fragmental rocks is very subtle and distinction between them is commonly difficult.

The mafic metavolcanic rocks extending from west of Moss Lake to the northeastern extremity of the map area are highly tectonized and recrystallized; therefore, in many places they can only be identified as amphibole-plagioclase schist or amphibolite. These metavolcanic rocks are bounded by Moss Lake Stock, to the southeast, and are juxtaposed to the northwest by the Quetico metasediments. The contact zone is sheared in many places. However, well-preserved, pillowed and massive flows in a few places along the length of the unit confirm the mafic volcanic protolith for rocks in the northeastern NMU. The NMU is intruded by numerous large and small mafic to intermediate sills and dikes. Metre-scale lenses of felsic metavolcanic rocks occur in the northeastern half of NMU.

Southern Mafic to Intermediate Metavolcanic Unit

The southern mafic to intermediate metavolcanic unit (SMU) occurs as a narrow belt in the southeastern part of the township (*see* Figure 2). The belt is bounded to the north by felsic to intermediate metavolcanic rocks and to the south by Hood Lake Syenite Stock. The SMU is chiefly comprised of massive mafic flows and mafic gneisses. Pillowed flows and fragmental rocks are apparently absent in SMU. Mafic gneiss occurs along the contact. The gneiss consists of alternating hornblende and plagioclase bands up to 2.5 cm thick. Adjacent to the contact with the stock, hornblende is porphyroblastic. The porphyroblasts are 1 to 2 mm and occur parallel to and crosscut the layering. Gneissic layering becomes less well developed outward from the intrusive contact with stock and gradually merges with the fine-grained, massive mafic flows. The mafic gneiss, which represents amphibolite-grade metamorphic facies is a contact-metamorphic aureole imposed upon greenschist-grade mafic metavolcanic rocks by the Hood Lake Syenite Stock.

Central Mafic to Intermediate Metavolcanic Unit

The central mafic to intermediate metavolcanic units (CMU) is a northeast-trending, approximately 1 km wide wedge, extending from the south-central township border to Pierce Lake (*see* Figure 2). The CMU is chiefly comprised of massive and pillowed flow units with associated pillow breccia and fragmental rocks. Along the strike, a small lens of strongly silicified, massive to pillowed flows and fragmental units containing iron formation occur in the Snodgrass Lake area. The source for fragmental rocks is interpreted to be similar to that of NMU fragmental rocks.

Central Felsic to Intermediate Metavolcanic Unit

The central felsic to intermediate metavolcanic unit (CFU) extends from the southern township boundary through north and south of Pierce Lake to Snodgrass Lake, swinging east-northeast towards Span and Fountain lakes, and finally to Burchell Lake in the northeastern part of the township (*see* Figure 2). The CFU has a mafic to intermediate metavolcanic wedge in the southern part of the township and narrow small lenses occur throughout the CFU.

The CFU is chiefly comprised of massive and porphyritic flows and associated flow breccias (autoclastic) of similar composition (dacite and rhyodacite). Coarse fragmental rocks are abundant east of Pierce Lake and are traceable to the Snodgrass Lake area. Small lenses of fragmental rocks also occur south of Wawiag River and on the north shore of Fountain Lake. Blocks of angular to subangular flow material occur in an aphanitic and well-sericitized ± chloritized and foliated groundmass. Block- to lapilli-size fragments make up 5 to 40% of the rock volume. Frequently, block- and lapilli-size material can be seen to represent much larger disintegrated fragments (greater than 1 m across). These coarse fragmental rocks may possibly represent proximal- to vent-facies flows and associated explosive breccias.

Chemical Metasedimentary Rocks

Iron formation and minor chert beds are commonly found in the mafic to intermediate metavolcanic succession. Two types of iron formation are found in the map area: 1) thinly bedded alternating chert + magnetite-banded iron formation; and 2) a rare fragmental iron formation unit comprising clasts of chert, magnetite and mafic metavolcanic rocks, in a carbonate-enriched clastic matrix, which occurs locally in the Huronian mine area and west of Moss Lake. The clasts vary from granule to boulder size. The larger fragments are generally vesicular mafic metavolcanic rocks. The fragmental iron formation is likely derived from underlying vesicular or amygdaloidal massive and pillowed mafic flows and chert-magentite-banded iron formation.

Alternatively, the fragmental iron formation may have been formed by tectonic processes. In the Huronian Mine area, the fragmental iron formation is exposed in the closely spaced high-strain zones and, as a result, iron formation is boudinaged, tightly drag folded and sheared. The shearing and tight drag folding of competent chert-magnetite beds along with less competent mafic to intermediate metavolcanic rocks may have been responsible for the fragmentation of iron formation.

Quetico Metasedimentary Rocks

The northeast-trending Quetico Subprovince metasedimentary rocks consist of massive to thinly bedded, weakly graded, wacke and minor thinly bedded to finely laminated siltstone. The wacke is generally comprised of quartz, mica and lithic fragments. Siltstones are well sorted and consist of plagioclase and minor quartz grains.

The Quetico metasedimentary rocks contain rare planar cross-beds and are weakly graded. Commonly wacke beds grade from fine grained to silt size. Silty tops of the beds are in sharp contrast with the overlaying wacke beds. Tops are dominantly northward but reversals are common and indicate the presence of minor and major folds. Top determinations from the southwest township boundary indicate that the Quetico metasedimentary rocks face south at the contact with the north facing Shebandowan metavolcanic unit (NMU).

Dikes and sills of several types transect the Quetico metasedimentary rocks. Feldspar porphyritic-diorite, diorite, leucogabbro, gabbro, feldspar porphyry and trondjhemite intrude along bedding planes. Late diabase dikes crosscut bedding at several locations.

Mafic to Intermediate Intrusive Rocks

Mafic to intermediate intrusive rocks include gabbro, leucogabbro, diorite, feldspar porphyries and related altered equivalents. Most of these intrusive rocks occur as sills but crosscutting dikes of all types are common. In large outcrops, gradation from gabbro to feldspar porphyry is commonly noted. No compositional layering was observed. The gradation from mafic gabbro to intermediate feldspar porphyry indicates possibly a similar source of origin for these rock types.

Gabbro is the dominant intrusive rock in NMU and the Quetico metasedimentary rocks. Diorite and associated feldspar porphyries are the most common intrusive rocks in the central felsic to intermediate metavolcanic host. A moderately magnetic, metamorphosed, mafic to intermediate intrusive body (*see* Figure 2) was mapped northwest of Burchell Lake where it has intruded the mafic metavolcanic rocks. The main rock types within this intrusive body include gabbro, plagioclase-phyric gabbro, amphibolite and diorite. Some of these intrusive rocks could possibly be coarse mafic flows. No compositional layering or gradation were observed on outcrop scale. Disseminations of sulphide mineralization (chalcopyrite and pyrite) was noted in a few outcrops.

Younger Metasedimentary Rocks

A few small exposures of conglomerate occur in the vicinity of the Minoletti trenches on the Nelson Lake Road. The conglomerate was first noted by Chorlton (1987) in the area. The conglomerate is polymictic, clast supported and contains subangular to subrounded clasts of felsic and mafic metavolcanic rocks and feldspar porphyry. Small amounts of pink latite also occur in some rocks. The clasts are cobble to boulder in size. In addition to this polymictic conglomerate outcrop, the present field party discovered more small exposures along strike. The oligomictic paraconglomerate is pale grey on a fresh surface and weathers whitish grey. About 10% rounded to subrounded pebble-size clasts of presently unknown material are set in a fine-grained greyish immature matrix. The conglomerate is schistose and parallels the 70° striking shear zone in the area.

Felsic Intrusive Rocks (Syenite and Related Rocks)

Three syenitic stocks, the Moss Lake, Hood Lake and Obadinaw stocks occur in the map area. The Moss Lake Stock is a composite intrusive body which extends northeast for approximately 7.5 km from the south shore of Moss Lake. The stock is up to 2.3 km wide and is elongated along strike. The stock ranges from true syenite to granite (greater than 20% quartz). Hornblende syenite is the most common rock type within the stock with rare biotite syenite. The syenite and related rocks are generally medium-grained, but fine-grained, megacrystic phases and layered phases are also present. Numerous xenoliths of country rocks occur ranging in size from 10 cm to 20 m. The layered unit consists of hornblende-rich bands up to 5 cm thick interlayered with potassium feldspar rich bands. Fluorite is found in several localities, most notably on Spruce Island of Moss Lake. Up to 3% magnetite occurs throughout the stock. The magnetite content of the stock is reflected by a relatively high magnetic signature (OGS 1991b). Disseminated pyrite is found in some localities.

The Hood Lake Stock is circular and lies south-southwest of Fountain Lake. Only the northwest portion of the stock is within the map area. The syenite of the stock is characteristically megacrystic hornblende ± pyroxene syenite with up to 20% biotite in some instances. Feldspar megacrysts from 0.5 cm to 10 cm long and up to 4 cm across make up between 60 to 80% of the rock volume. The megacrysts are generally aligned to the regional strike. Hornblende ± pyroxene is found interstitial to the feldspar megacrysts. The syenite along the contact with the southern mafic to intermediate metavolcanic rocks is gneissic (augen-gneiss).

Up to 5% magnetite is common throughout the stock. Pyrite is found as disseminated grains in the syenite in several localities. The Hood Lake syenite was emplaced along major fault planes in the metavolcanic rocks of Wawa Subprovince and because of its relatively undeformed nature, it was probably emplaced after most of the regional deformation had already taken place (Schwerdtner 1986).

The Obadinaw Stock northwest of Rainbow Lake is largely covered by sand and gravel and is poorly exposed.

The Obadinaw Stock differs from the Moss Lake and Hood Lake syenite stocks in that it ranges from a feldspar porphyritic syenite with less than 5% hornblende megacrysts to a hornblende porphyritic syenite with up to 90% hornblende. The phenocrysts are, on average, 1 cm long. Another melanocratic phase of the Obadinaw Stock is a biotite-rich syenite.

Pegmatitic patches and veins of potassium-feldspar are found in the syenite and the surrounding metasedimentary rock. Feldspar crystals in veins measure up to 7 cm long and 3 cm across. Numerous syenite dikes cut the surrounding metasedimentary rocks and are probably offshoots of the main stock. These dikes contain up to 10% muscovite and are thought to have derived from the partial melting of the metasedimentary host rocks.

Very little quartz is noted in the Obadinaw Stock. Magnetite occurs in patches and makes up to 5% of the rock volume.

Metasedimentary inclusions occur in the stock and are recrystallized. The recrystallized inclusions are similar to the metasediments which surround the stock.

The Obadinaw Stock also appears to be emplaced along zones of weakness similar to those controlling emplacement of the Moss Lake and Hood Lake syenite stocks.

Diabase Dike

Diabase dikes are the youngest intrusive rocks in the map area. They intrude all major rock types. The dominant trend of these dikes is north to northwest; rare east-striking dikes also occur. The diabase dikes are reddish brown on the weathered surface and light to dark grey on fresh surface. They are fine-grained to aphanitic. The texture is generally diabasic with feldspar (plagioclase) laths less than 1 mm. They contain up to 10% magnetite. The dikes are unfoliated. To the west and northwest of the map area, the northwest-trending dikes, reported here, may be part of a Keweenawan dike swarm (1.1 Ga; Osmani, in press). No radiometric data is available for the dikes within the map area.

METAMORPHISM

The bulk of the Shebandowan metavolcanic rocks have been metamorphosed to lower greenschist facies. Mafic metavolcanic rocks contain chlorite and albite while the felsic metavolcanic rocks contain chlorite and sericite.

Metamorphic grade within the Shebandowan metavolcanic rocks increases proximal to the large syenite stocks (Moss Lake and Hood Lake). Mafic metavolcanic rocks proximal to these stocks are banded and hornblende porphyroblastic. They contain a dark green to black hornblende and plagioclase assemblage, reflecting the amphibolite-grade contact metamorphic aureole imposed during the emplacement of the syenite stocks. In the northeastern portion of the NMU brown-red garnet was also noted in an outcrop, approximately 400 m from the contact of the Moss Lake Stock.

Quetico metasediments display recrystallized textures and a well-developed foliation defined by biotite orientation proximal to these large intrusions.

In the extreme northwestern extremity of the map area, granite and trondhjemite dikes are abundant. Recrystallization in metasedimentary rocks similar to that noted near the syenite stocks, increases in prominence to the northwest. Approximately 3 km north of the northwest township boundary, Harris (1970) has mapped migmatites.

STRUCTURAL GEOLOGY

Primary Structures

Bedding in the Quetico metasedimentary belt generally strikes northeast and dips steeply to the northwest. Minor dip reversals are also noted. Stratigraphic younging directions determined from graded bedding in the Quetico metasediments generally young northward; however, southward younging is also observed in many places, more specifically closer to the contact of the Quetico metasediments with the NMU towards the western part of the township. Tops determined from pillows and the architecture of individual flow units in NMU and CFU suggest stratigraphic younging to the north.

In the western part of the township, Quetico metasediments face southward near the contact with the NMU. The NMU in that area generally faces northward. The opposing facing directions of the Quetico metasediments and the NMU probably suggest tectonic juxtaposition of unrelated sequences along the faulted contact.

Folding in the Quetico metasediments appears to be isoclinal with thickened hinge areas and attenuated and truncated limbs on an outcrop scale. Fold closures occur on a small scale with changes in bedding attitudes taking place over a few metres. Numerous isoclinal folds of S, Z and M symmetry are common in the Quetico metasediments and to a lesser extent in the NMU. Boudinage and pinch and swell structures are common in the Quetico metasediments and less common in NMU. These features may indicate limb attenuation associated with the isoclinal folding.

Foliation and Lineation

Pervasive foliation and lineation are present proximal to the major shear zones and topographic lineaments. The foliation is less well developed outward from these zones and the lineation disappears. Chlorite and sericite mineral lineations in schistosity planes show shallow plunges (5° to 30°) to the southwest. Rare examples of northeast plunge also exist. Crosscutting mineral lineations are also noted in a few places. For example, the island on Snodgrass Lake, a late shear-related mineral lineation crosscuts an earlier subhorizontally plunging (5°) mineral lineation. Movement on the shears is sinistral and marked by tails of rotated fragments.

Shear and Fault Zones

The predominant structural imprint in the map area is numerous northeast to east-northeast-striking (40° to 70°), steeply dipping, ductile to brittle shear and fault zones. Many of these observed structures are coincident with topographic lineaments. Late shear and brittle faults trending northwest, east and north are also common, but they are less extensive compared to northeast-striking shear zones. The northeasterly-striking shear zones with sinistral sense of movement, are locally offset dextrally by east, northwest and north-trending brittle shear fractures and faults. On outcrop scale, these structures are of variable orientation and appear to be a conjugate shear/fault system. Many of these structures are spatially associated with gold mineralization in the map area, (e.g., Snodgrass Lake Prospect (Chorlton 1987) and Span Lake gold showing).

Many large-scale, anastomosing shear zones can be traced for several kilometres on recently released airborne magnetic and electromagnetic maps (OGS 1991b). The shear zones on these maps are marked by long, linear zones of low to medium magnetic intensities and some of them are coincident with trains of weak to medium strength electromagnetic conductors. These conductive zones may have the potential of hosting base-metal and gold mineralization. The best example of the shear/fault system exists in the southern part of the township, where many of these structures can be traced for several kilometres to the Snodgrass and Span Lake areas. These and many other structures in the map area are good regional targets for gold and base-metal mineralization.

ECONOMIC GEOLOGY

Some general observations of the field relations in key outcrops are discussed below.

In the Span Lake area, at the Central Crude Limited–INCO Limited gold showing, a pink (feldspathized?), sericitized host rock (felsic porphyritic flow?) is intruded by feldspar porphyritic and equigranular diorite. Felsic metavolcanic rock and diorite are cut by northeast (40° to 50°) and east-northeast (60° to 70°) striking, steeply dipping, ductile to brittle, curvilinear shear zones. The felsic volcanic rock, where cut by the shear zone, is altered to quartz + sericite ± chlorite schist. The sericitized schist subtly passes into a strongly feldspathized portion of the outcrop. The feldspathized rock strongly resembles syenitic intrusions in the area. Sulphides (chalcopyrite and pyrite) occur in the feldspathized rock along fractures/shear planes and also disseminated throughout the rock. Occasional mafic clots (amphibole phenocrysts now altered to chlorite?) also contain sulphides. In quartz + sericite ± chlorite schist, the sulphides occur along shear planes as narrow massive seams. Diorite, where cut by shear zones, is rusty and contains sulphides along shear planes.

Similar alteration types, lithologic package and structures are also observed at the Snodgrass Lake prospect of the Tandem Resources—Storimin Exploration Limited–Central Crude Limited. At Snodgrass Lake, the feldspar porphyry and diorite intrude felsic metavolcanic rocks. A small hornblende-quartz-syenite intrusion cuts both the diorite and felsic metavolcanic rocks. These rocks are traversed by northeast (40°) to east-northeast (60° to 75°) striking steeply dipping fissile shear zones. Late brittle faults and fracture sets of variable orientation cut earlier shear zones. The felsic metavolcanic rock is sericitized and sulphidized along shear planes. Diorite shows epidotization and silicification and it is schistose in places. Disseminated pyrite and chalcopyrite occur in shears and associated fractures in diorite. The syenite intrusion is also cut by east-northeast-trending shear zones. Altered amphibole (chlorite?) phenocrysts in syenite are associated with fine-grained pyrite and chalcopyrite.

At the Snodgrass Lake prospect, gold values of up to 1650 ppb and 370 ppb have been reported (Chorlton 1987) from highly sheared/fractured diorite and felsic metavolcanic rock, respectively. An anomalous gold value (90 ppb) is also reported from the syenite intrusion (Chorlton 1987). Chorlton (1987) reported up to 24.6 ppm gold from small quartz-carbonate-albite veins and 2750 ppb gold from a wall-rock schist adjacent to one of the veins.

Representative assay samples collected from both the Snodgrass Lake Prospect and Span Lake area by this field party have been submitted to the Geoscience Laboratories, Ontario Geological Survey, Toronto. The results from these samples are pending.

The lithologic package, associated alteration types and structural style as discussed previously were also observed by the authors at other locations, especially southwest and east of the Snodgrass Lake area (Figure 2). Several northeast-trending shear zones, extending from the south border of the township through the south end of Snodgrass Lake and northeastward to Span Lake, appear to play an important role in localizing gold mineralization as shown in Figure 2. These gold occurrences are documented in the Assessment Files Research Office, Ontario Geological Survey, Toronto, as well as in the Resident Geologist's Office, Thunder Bay.

Mineralization style in the northern metavolcanic unit (NMU) is different from the central mafic to intermediate (CMU) and felsic to intermediate (FMU) metavolcanic units. Gold mineralization in the NMU occurs within and around quartz ± carbonate veins which are situated along northeast-trending shear zones (e.g., Huronian Mine, Minoletti and Beaver zones). The auriferous quartz vein at the Huronian Mine is hosted by chlorite + sericite + carbonate schist. A feldspar porphyry is closely associated with the quartz vein. Quartz vein is known to contain pyrite, chalcopyrite, galena, sphalerite, tellurides and small amount of native gold (Harris 1970).

Shear-zone-hosted gold mineralization potential exists within the NMU and along the contact with the Quetico metasediments. Weak- to medium-strength electromagnetic conductors, albeit discontinuous, occur along the contact zone (OGS 1991b). The contact zone is either strongly sheared or marked by prominent topographic lineaments. Several samples were collected for assay by the present field party along the contact zone. Results from only five samples are available at this time; others are still pending. The samples of sheared gabbro, feldspar porphyry and metasediments from the southwestern contact zone, north of Obadinaw River, have yielded 16 ppb, 55 ppb and 10 ppb gold, respectively (Geoscience Laboratories, Ontario Geological Survey, Toronto). Two samples of sheared gabbro collected from northeastern part of the contact zone (about 3.5 km northeast of Rainbow Lake) have yielded 39 ppb and 175 ppb gold (Geoscience Laboratories, Ontario Geological Survey, Toronto).

In the extreme northeast corner of the township, a northeast-trending shear zone cuts the amphibolitized mafic metavolcanic and gabbroic rocks. These rocks are highly oxidized and contain sulphides (pyrite, pyrrhotite) and magnetite. Medium- to high-strength electromagnetic conductors are coincident with the sheared amphibolites. These sulphidized, sheared rocks should be explored thoroughly for possible gold and base-metal mineralization.

A northeast-trending, long, narrow, gabbro sill complex in the middle of the Quetico metasedimentary belt should be explored for base-metal and gold mineralization. Gabbro is the dominant rock type within the mafic sill complex. Other minor phases include leucogabbro, amphibolite and diorite. The contact of the sill with the metasedimentary rocks is either sheared or marked by topographic lineaments. Trains of medium- to high-strength electromagnetic conductors (OGS 1991b), which occur along its entire strike length, have potential for possible base-metal and gold mineralization. Two assay samples of sulphide-bearing (pyrrhotite, pyrite) sheared gabbro have been submitted to the Geoscience Laboratories, Ontario Geological Survey, Toronto. The results from these samples are pending. To the west, just outside the township boundary, a copper occurrence has been reported in a sheared diorite body of this sill complex (Harris 1968, 1970).

A mineralized (chalcopyrite, pyrite) plagioclase-phyric gabbro to diorite from a mafic to intermediate intrusive body, situated northwest of Burchell Lake, was sampled for assay by the present field party . This sample has yielded trace levels of gold (4 ppb), platinum (2 ppb) and palladium (5 ppb) (Geoscience Laboratories, Ontario Geological Survey, Toronto). Results of other samples taken from this intrusive body are still pending. Approximately 300 m east of the township boundary, north of Burchell Lake, a gold-platinum occurrence has been reported (GDIF, Resident Geologist's Office, Thunder Bay).

ACKNOWLEDGMENTS

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Special thanks are extended to P. Thurston (Senior Research Scientist, Ontario Geological Survey, Toronto) for advice on depositional environments of some volcanic units.

Last but not least, we acknowledge the competent assistance provided in the field by V. Bannister and Y. Renes.

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52. Industrial Minerals and Building Stone in the Districts of Nipissing, Parry Sound and Sudbury

C. Marmont

Ministry of Northern Development and Mines, Dorset

INTRODUCTION

A program to evaluate the economic potential of industrial minerals and building stone in the district of Parry Sound and parts of the districts of Nipissing and Sudbury commenced in April, 1991. The three districts are within that part of the province designated as "Northern Ontario", and as such are eligible for enhanced incentives for development. The study area is limited to areas of Grenvillian geology; consequently, only those parts of Sudbury and Nipissing districts which lie south of the Grenville Front Tectonic Zone are included. The study area includes parts of three Resident Geologists' districts; they are defined approximately as follows: Algonquin District south of French River–North Bay–Mattawa; Cobalt District north and east of North Bay; and Sudbury District north of French River and west of North Bay. The project will be completed by the autumn of 1993.

CURRENT PRODUCTION AND EXPLORATION ACTIVITIES

There is intermittent production of dimensional black granite in Dana Township; production of building stone and flagstone ("Mica Stone") continues in the Thorne–Eldee area (Basa 1991); and granitic flagstone and veneer are produced at Parry Sound. Private sector evaluation of dimensional granitc gneiss and flagstone continues throughout the area.

Silica is quarried in Cosby Township for use as a flux at INCO's Sudbury smelting operations.

Soda spar is produced from pegmatite in Mattawan Township near Mattawa.

Graphite is produced at Cal Graphite Corporation's mine in Butt Township.

A kyanite deposit at Crocan Lake, northeast of North Bay, is in the early stages of development.

PREVIOUS WORK

A study of industrial minerals and building stone in Parry Sound District and the southern part of Nipissing District has been reported by Martin (1983) and Marmont (1991). A study of industrial minerals and building stone in the Sudbury–North Bay area was reported by Vos et al. (1981), while Lacey (1989, 1991) described dimensional stone activities in the Sudbury District. The kyanite deposits at Crocan Lake, near Mattawa, have been described by Hewitt (1952) and Vos et al. (1981). Vos (1978) described silica occurrences south of Sudbury.

Geological maps at a scale of one inch to one mile are available for the area north of latitude 46°N (Lumbers 1971a, 1971b, 1971c, 1972, 1973, 1974, 1975, 1976a, 1976b). Parry Sound District has been mapped at a scale of 1:250 000 by Davidson et al. (1982). Larger scale maps of parts of the District are by Satterly (1956), Lacy (1960), Bright (1990), McRoberts and Tremblay (1991), McRoberts (1991), Macfie and Dixon (1990), and Culshaw et al. (1988, 1989, 1990).

CURRENT PROGRAM

Literature Review

A review was made of published reports and the recently compiled GED (Geoscience Exploration Data) files to determine the type and distribution of mineral commodities throughout the study area, and to formulate priorities for field investigations.

Industrial minerals known to occur in the area include silica (in quartzite and pegmatite), flake graphite and kyanite in pelitic and semi-pelitic gneiss, garnet (in biotite gneiss), feldspar (in pegmatite, nepheline syenite and anorthosite), gabbro-diabase, vermiculite, carbonates (limestone, marble and carbonatite), mica and building stone.

After considering the current balance of supply and demand for the various commodities, current local developments (notably in kyanite and graphite), and the geology of the

This project is funded under the Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Canada-Ontario Economic and Regional Development Agreement.

known occurrences in the area, it was concluded that quartzite, mica and building stone represented the commodities most likely to present economically interesting targets. Subsequent field work has concentrated on these commodities.

Field Work

Field work is ongoing at the time of writing. To date, most of the work has been of a reconnaissance nature, with the objective of defining more specific courses of study for some of the industrial minerals; and systematically surveying for potential building stone.

BUILDING STONE

There is good potential for large-block dimensional granite and thinly splitting gneissic granite in the study area. Systematic surveys for dimensional granite have previously been reported in Sudbury and Parry Sound districts (MNDM, 1989; Lacey 1989, 1991; Marmont 1991). Fouts and Marmont (1989) and Marmont (1991) describe known flagstone quarries and exploration criteria for such stone, but no systematic surveys have been performed in the project area to identify additional specific resources. Field work in 1991, therefore, commenced with field evaluation of dimensional granite in the Cobalt Resident Geologist's district, and of flagstone in the whole area.

To date, one potential dimensional granite prospect has been identified in a pink granite near Marten River, and an attractive, good-splitting flagstone identified northeast of Burk's Falls. This reconnaissance programme is continuing at the time of writing.

Visits were made to current flagstone quarries at Eldee and Parry Sound. Mr. Paul Pharand produces a micaceous flagstone veneer at Eldee, while Mr. George Boughner produces rough chunks of green, red and satin "Mica Stone" which is a popular veneer. Some of Mr. Boughner's satin stone contains perhaps 30% of colourless muscovite mica. The stone can be crushed easily and may constitute a source of mica.

The Mill Lake Stone Quarry at Parry Sound continues to operate at capacity, supplying this premium stone to a wide market area.

Prior to the field season, the feasibility of conducting a market study for thinly splitting gneisses was investigated. This was prompted by the qualitative conclusion reached by Fouts and Marmont (1989) that there was good potential to supply far more gneissic granite flagstone and veneer to the large markets of southern Ontario than is currently being acheived. Furthermore, enquiries are frequently received at the Algonquin Resident Geologist's office regarding opportunities for quarrying and marketing of local stone.

Discussions with several members of the stone trade in southern Ontario confirmed the earlier conclusions. They felt that far more "Muskoka Stone" could readily be sold in the greater Toronto area. The two main impediments to greater sales are limited supply of stone and shortage of workers trained in the installation of stone (J. Melo, President, Allstone Quarry Products, Schomberg, personal communication, 1991).

The supply of stone is limited by current quarry capacity rather than reserves of stone, which are plentiful.

Many stone masons prefer to work with brick or concrete block. When installing stone, they raise their price two- or threefold, thereby reducing demand for stone. This situation is unnecessary and could be remedied by suitable stone masonry courses. Joe Melo has been been conducting such courses over the last few years.

In the light of such comments, it was decided that a formal market study would not serve a useful purpose at this time. However, it is apparent that the stone industry in Ontario is fragmented, information is not readily disseminated within and between the various sectors, and the use of stone is not actively promoted. There appears to be a need to develop a co-ordinated approach to the extraction and utilization of stone within the province.

KYANITE

A visit was made to the Crocan Lake Kyanite deposit in Butler Township, some 50 km northeast of North Bay. The deposit was discovered in 1951, and has been described by Hewitt (1952) and Vos et al. (1981).

The property is owned by the Kyanite Mining Corporation, which currently produces kyanite from mines in Virginia. Reserves of coarse-grained kyanite at Crocan Lake are estimated at approximately 50 million tonnes with a grade of between 10% and 15%. Beneficiation tests are underway, and application has been made to develop a hydro power plant for the mine and mill on the Jocko River, some 3 km to the north. The company expects to produce a coarse-grained product to complement its current output.

A kyanite occurrence near Wanapitei, southeast of Sudbury was also visited by the author. These deposits have previously been described by Pearson (1962) and Vos et al. (1981).

No further work on kyanite is planned in this study.

GRAPHITE

Graphite is an important industrial mineral which is widespread in central Ontario. Cal Graphite Corporation is currently producing high-purity coarse flake graphite from its mine in Butt Township, north of Huntsville. Graphite is also produced in southwestern Quebec, and several deposits in Quebec and Ontario are at an advanced stage of evaluation. The near-term potential supply of graphite is therefore very high, and could conceivably exceed demand. Therefore, no further work on graphite is planned within the framework of this study.

NEPHELINE SYENITE AND FELDSPAR

Hewitt (1961) and Duke and Edgar (1977) have described the nepheline syenite body in Bigwood Township near French River. Additional work on nepheline syenite resources is not timely because existing producers are operating below capacity, since nepheline syenite has lost market share to plastic and aluminium in the container industry.

Soda spar is currently produced in small quantities from pegmatites near Mattawa and shipped to Germany (Basa 1991; Harding 1944).

Numerous other pegmatites are known within the study area (Goad 1990; Hewitt 1967; Vos et al. 1981; Marmont 1991), some of which have produced feldspar in the past. However, most are small, and/or partly worked-out, and thus unlikely to represent significant economic resources. Some may be suitable as mineral-collecting sites or for decorative stone or aggregate. No further examination of pegmatites in the study area is planned.

Several anorthosite/gabbroic anorthosite bodies occur within the study area. Some have previously been described by Marmont (1991); others may be investigated in order to complement this previous information. The high aluminum-high calcium feldspar of anorthosite may find applications in the ceramics, glass and insulation industries, as an abrasive, and as a source of aluminium sulphate for water purification.

SILICA

Quartzite is quarried in Cosby Township and shipped to Sudbury for use in INCO's smelting operations. Similar quartzites occur in Delamere and Secord townships, and have previously been described by Lumbers (1975) and Vos (1978). The quartzites contain minor amounts of specular hematite, feldspar, muscovite and sillimanite. The quartzite is crushed to -2 mesh for use as a flux. Finer washed material and screenings are used as road and decorative aggregate.

Similar quartzites occur northeast of North Bay in McAuslan, Clarkson and Poitras townships (Lumbers 1971b; Basa 1991). Samples have been collected for analysis from some of these occurrences.

VERMICULITE, GARNET, CARBONATES

No field work has yet been conducted on these commodities. Field checking of some sites will be undertaken in order to determine whether further investigations are warranted.

PROPOSALS FOR FURTHER WORK

Field work will continue to evaluate dimensional granite and gneissic flagstone throughout the study area. The granites in the area are remarkable for their diversity of colour and texture. Stones which possess unusual or distinctive characteristics are becoming increasingly popular on the world market, suggesting a need to conduct more detailed surveys in certain parts of the study area. Since silica, graphite and kyanite deposits are currently being exploited or are at an advanced stage of evaluation, there appears to be little justification for further work in these commodities.

Further work on vermiculite, garnet, carbonates and feldspar is pending.

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53. The Industrial Minerals Program in Northwestern Ontario

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INTRODUCTION

The "Industrial Minerals" program was initiated in March, 1991, to stimulate exploration, development and production of industrial minerals in northwestern Ontario. This program is jointly funded by the four-year Northern Ontario Development Agreement, a subsidiary agreement to the Canada-Ontario Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario. The primary objectives of the program are: to document and investigate new and previously-known industrial mineral occurrences; to provide client services via property visits, sample analyses and information exchange; introduce public education through prospector classes, oral presentations and poster displays; and increase awareness of northwestern Ontario industrial minerals at technical seminars, workshops and conferences.

MINING ACTIVITY

Currently, five industrial mineral commodities are being produced in northwestern Ontario. Pink granite is produced at two quarries, Nelson Granite Ltd. and Granite Quarriers (G.Q.I.) Inc., west of Vermilion Bay. Railway ballast is produced for Canadian National Railways at the Watcomb quarry east of Sioux Lookout. Canadian Pacific Railways obtains ballast material from a quarry at Dyment, east of Dryden. Diabase is quarried northeast of Thunder Bay by L.T.L. Contracting for use as rip rap in soil erosion projects. Finally, soapstone blocks are extracted by Phil Thorgrimson, from the former Grace Mining Company quarry on Eagle Lake, southwest of Dryden.

FIELD WORK

A total of 31 field visits (Figure 1, 2 and 3; Table 1), representing 18 industrial mineral commodities, were conducted to locate, sample, examine and record high potential occurrences. The following sites were sampled to evaluate their dimension-stone potential:

1. pink quartz monzonite on the LeMay road, northwest of Manitouwadge
2. white granodiorite from the Dotted Lake area (Schnieders et al. 1991, p.162-168), south of Manitouwadge
3. red quartz monzonite at Pearl Lake in McTavish Township
4. two samples of pink and white granite were obtained from a location alongside the Nipigon River, west of Lake Helen
5. buff-coloured limestone in the Poshkokagan River area
6. buff and red marbles from Hughes Point on Nipigon Bay
7. black and red granites from past-producing quarries, northwest of Marathon.

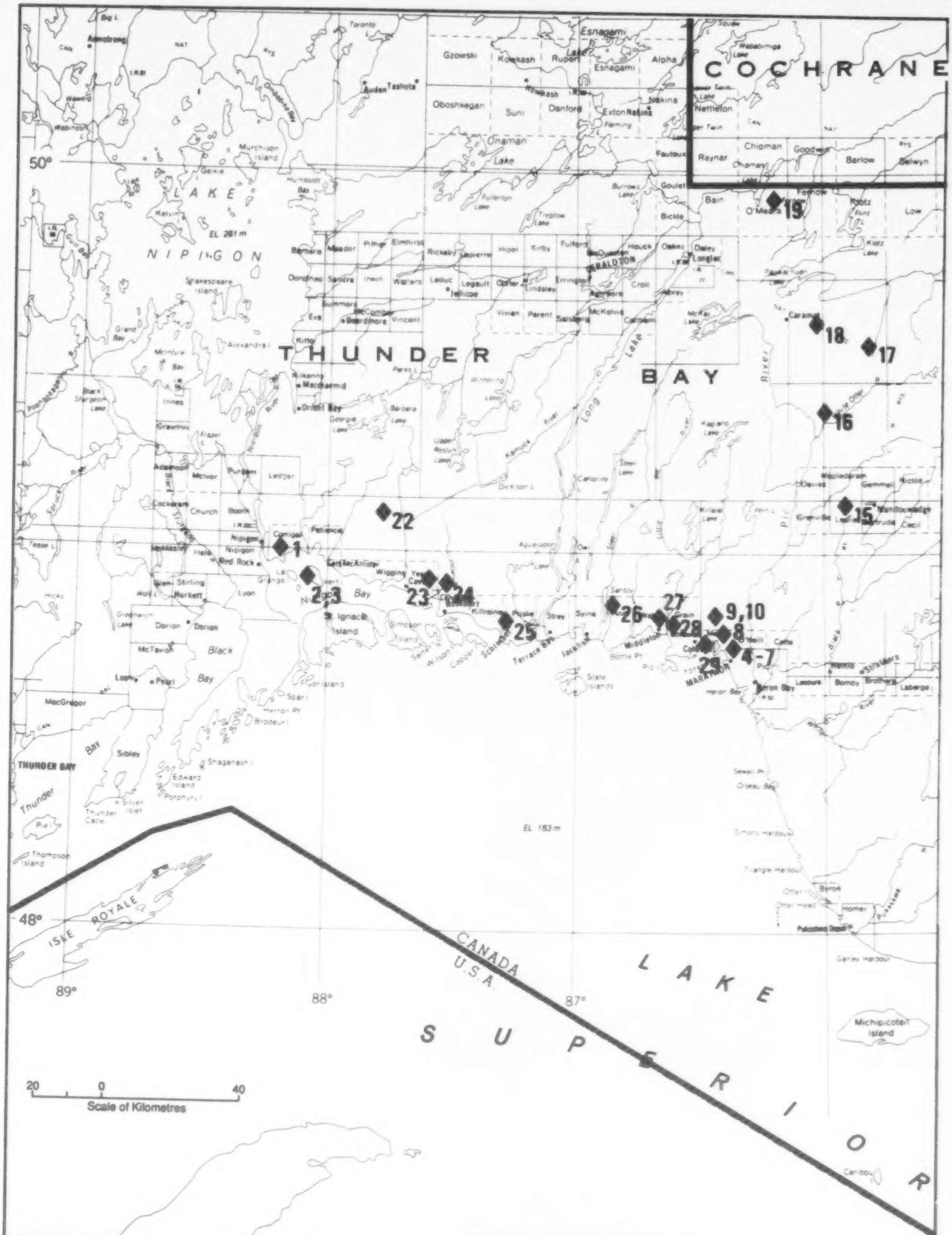
Samples were cut and polished to evaluate their attractiveness and ability to take a finish. Further field work will be conducted to establish field parameters required for potential dimensional-stone sites.

OTHER ACTIVITIES

A display, entitled "Industrial Mineral Activities in Northwestern Ontario", was presented at the Thunder Bay Mines and Minerals Symposium in April, 1991, and at the Institute on Lake Superior Geology in Eau Claire, Wisconsin, in May, 1991. Oral presentations, dealing with prospecting for industrial minerals, were presented at information sessions and classes for prospectors in the following communities: Manitouwadge, Marathon, Terrace Bay, Nipigon and Thunder Bay. Other activities included attendance at a seminar entitled "Geophysical Solutions to Geologic Problems of Continental Interiors: A Minnesota Workshop" which was held in Minneapolis, Minnesota; and participation in presenting a Mining Sequence display in Manitouwadge and Thunder Bay.

CANADA ONTARIO
Minerals • Minéraux

This project is funded under the Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Canada-Ontario Economic and Regional Development Agreement.


COCHRANE
LAKE NIPIGON
THUNDER BAY
LAKE SUPERIOR
CANADA
U.S.A.
ISLE ROYALE
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89°
88°
87°
EL 281 m
EL 183 m
Esnagami Lake
Onaman Lake
Long Lake
GERALDTON
Longlac
Nakina
Jellicoe
Beardmore
Nipigon
Red Rock
Schreiber
Terrace Bay
Marathon
Heron Bay
Pic River
Black Bay
Thunder Bay
St. Ignace Island
Slate Islands
Michipicoten Island
Caribou I.
Pukaskwa Depot
Otter Head
Simons Harbour
Oiseau Bay
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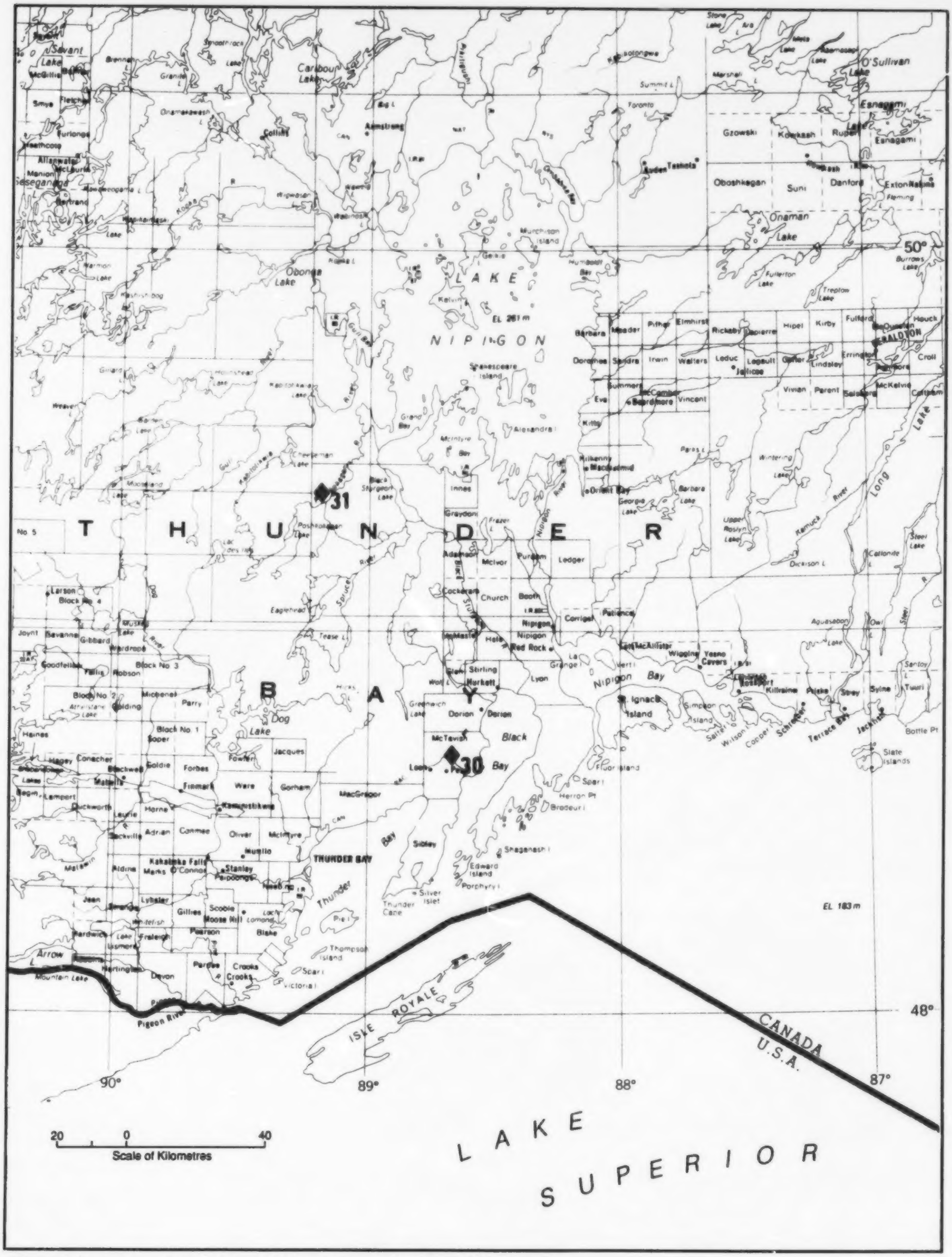
Scale of Kilometres

Figure 1. Northwestern Ontario Industrial Minerals Program. ◆ Property Visits, 1991 (keyed to Table 1).


LAKE NIPIGON
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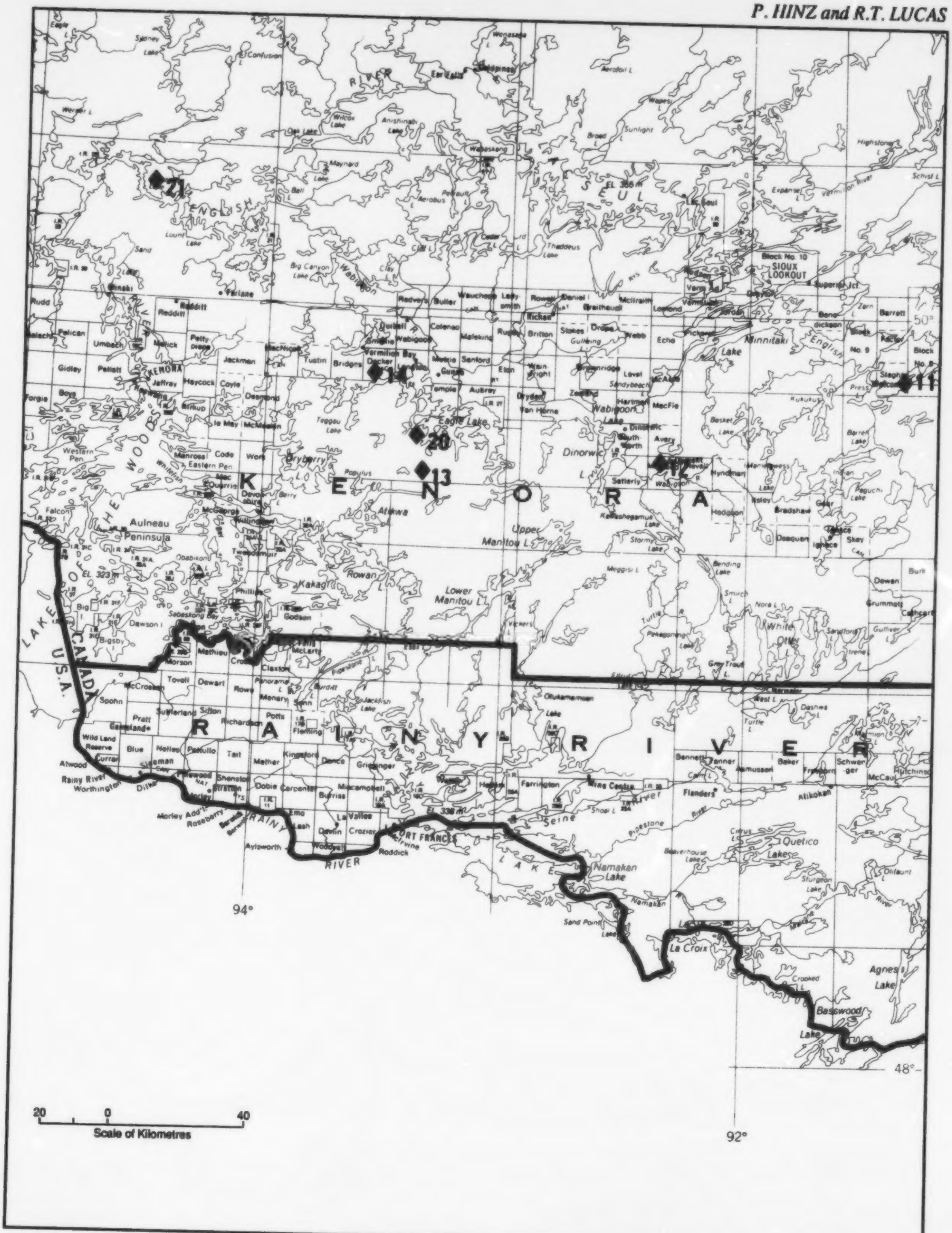
30
THUNDER BAY
Nipigon Bay
Black Bay
Thunder Bay
ISLE ROYALE
CANADA
U.S.A.
LAKE SUPERIOR
EL 183 m
50°
48°
90°
89°
88°
87°
20
0
40
Scale of Kilometres
Geraldton
Nipigon
Red Rock
Dorion
Schreiber
Terrace Bay
Jackfish
Armstrong
Collins
Savant Lake
Caribou Lake
Obonga Lake
Ombabika Bay
Long Lake
Onaman Lake
Dog Lake
Arrow Lake
Pigeon River
Sibley
St. Ignace Island

Figure 2. Northwestern Ontario industrial Minerals Program (*see* Figure 1 for legend).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K E N O R A
R A I N Y R I V E R
LAKE OF THE WOODS
U.S.A.
CANADA
SIOUX LOOKOUT
KENORA
Dryden
Vermilion Bay
Eagle Lake
Wabigoon Lake
Dinorwic
Upper Manitou L.
Lower Manitou L.
Aulneau Peninsula
FORT FRANCES
Rainy River
Atikokan
Quetico Lakes
Namakan Lake
La Croix
Basswood Lake
Agnes Lake
Lac Seul
English River
50°
48°
94°
92°
20
0
40
Scale of Kilometres

Figure 3. Northwestern Ontario Industrial Minerals Program (*see* Figure 1 for legend).

Table 1. Industrial Mineral Property Examinations—1991

1. Ruby Hill[1] – marble
2. LaGrange Island – red sandstone
3. Vert Island – red sandstone
4. C.S. Downey (Shack Lake) – labradorite
5. Angler quarry – black granite
6. Peninsula quarry – red granite
7. Coldspring quarry – brown granite
8. Port Munroe – niobium
9. Marathon occurrences – niobium
10. Geordie Lake[1] – radiometric survey
11. Watcomb quarry[2] – railway ballast
12. Dyment quarry[2] – railway ballast
13. Crystal Quarries Ltd.[2] – crystal quartz
14. Granite Quarriers Inc.[2] – pink granite
15. Swill Lake[1] – garnet
16. LeMay Road – quartz monzonite
17. Taradale Lake – graphite
18. Little Charon Lake – graphite
19. Chipman Lake – rare-earths, niobium
20. Eagle Lake[2] – soapstone
21. Treelined Lake – graphite
22. Cypress Lake[1] – radiometric survey
23. Halonen occurrence – fluorite, barite
24. Pays Plat – barite
25. Lafontaine fluorite – fluorite, barite
26. Santoy Lake[1] – radiometric survey
27. Dead Horse Creek[1] – rare-earths
28. Renshaw-Tripp – titanium
29. Coldwell Lake – nepheline syenite
30. Pearl Lake quarry – red granite
31. Poshkokagan River – limestone

[1] *visited during a field trip conducted in 1991*
[2] *currently producing*

FUTURE WORK

Future work will include the preparation of an Open File Report on industrial-mineral occurrences in northwestern Ontario. Classes and seminars will be given to inform and educate prospectors on both industrial-mineral opportunities and prospecting techniques for industrial minerals. Project results and recommendations will be presented in the Report of Activities 1991, Resident Geologists, which is published in a Miscellaneous Paper format; this annual report is scheduled for release by the Ministry of Northern Development and Mines in March, 1992.

ACKNOWLEDGMENTS

This report was edited by K.G. Fenwick and reviewed by B.R. Schnieders. M.C. Smyk provided assistance on a number of property visits in the Marathon area and supplied invaluable information on the geology of the Coldwell complex. C. Komar reviewed this report and provided professional and efficient secretarial support throughout the year along with S. Warren. B. Nelson, Assistant Drill Core Library Geologist, was responsible for the preparation of the voluminous quantity of samples required by this program. Assistance in the field and office was provided by B. Lucas whose efforts are gratefully appreciated. Numerous company representatives and prospectors provided invaluable information and field assistance on industrial-mineral occurrences throughout northwestern Ontario.

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54. The Manitouwadge Mineral Resource Geologist Project

D.B. McKay

Regional Mineral Resources Section, Northwestern Ontario, Thunder Bay

INTRODUCTION

The Manitouwadge Mineral Resource Geologist Project was initiated in January, 1991, to stimulate and facilitate mineral exploration and development within a 50 km radius of the township of Manitouwadge (Figure 1). Primary objectives include the compilation, research and investigation of new and previously known mineral occurrences in the Manitouwadge area; preparation of an Open File Report documenting these occurrences; provision of client services via property examinations, field trips, sample analyses and information dispersal; and provision of public education via

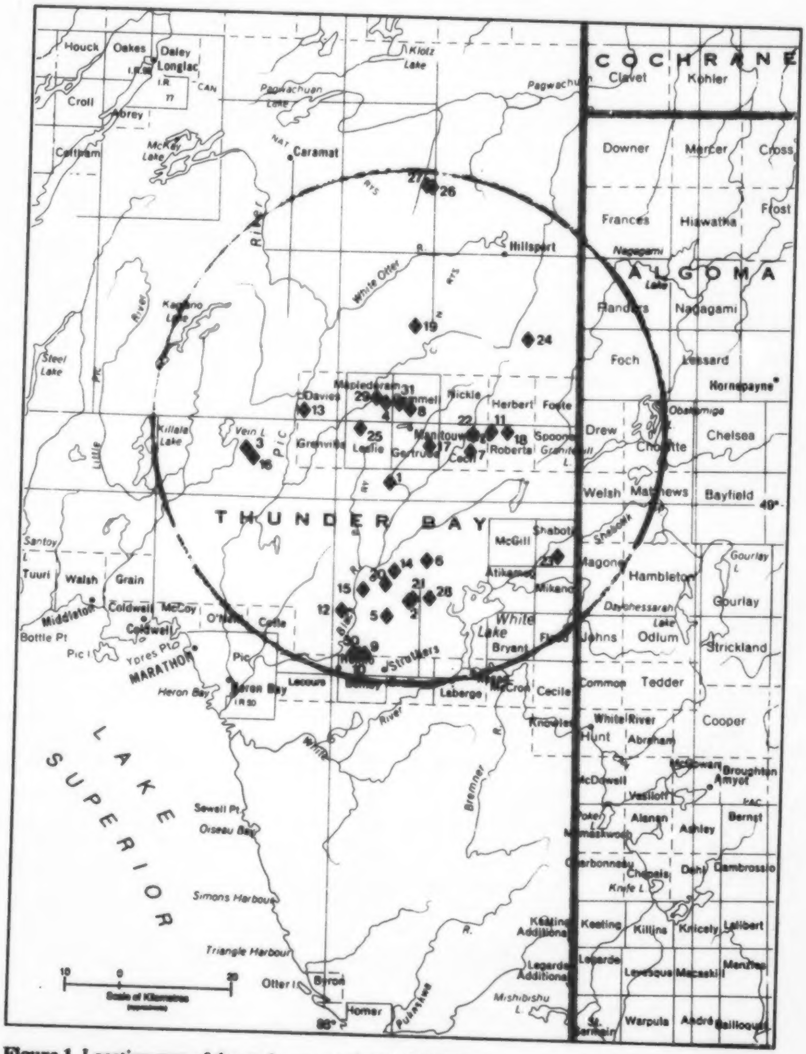
COCHRANE
ALGOMA
THUNDER BAY
LAKE SUPERIOR
Houck
Oakes
Daley
Longlac
Croll
Abrey
Caramat
Klotz Lake
Pagwachuan Lake
Clavet
Kohler
Downer
Mercer
Cross
Frances
Hiawatha
Frost
Hillsport
White Otter
Nagagami
Flanders
Foch
Lessard
Hornepayne
Davies
Mapledoram
Gemmell
Nickle
Herbert
Foote
Killala Lake
Vein L.
Grenville
Leslie
Gertrude
Manitouwadge
Cecil
Roberta
Spooner
Drew
Obatanga
Chelsea
Welsh
Mathews
Bayfield
McGill
Shabotik
Magone
Hambleton
Gourlay
Santoy
Tuuri
Walsh
Grain
Coldwell
McCoy
Middleton
Bottle Pt
Pic
MARATHON
Heron Bay
Heron Bay
Pic
Lecours
Laberge
McCron
Cecile
White Lake
Bryant
Odlum
Strickland
Johns
Tedder
Cooper
White River
Hunt
Abraham
McDowell
Broughton
Amyot
Sewell Pt.
Oiseau Bay
Simons Harbour
Triangle Harbour
Otter I.
Byron
Homer
Pukaskwa
Bremner
Mishibishu L.
Keating
Killins
Knicely
Lalibert
Legarde
Levesque
Macaskill
Menzies
Warpula
André
Baillooquet
Dehi
Gambrossio
Chapais
Knife L.
Alanen
Ashley
Bernst
Poker
Vasiloff
Cartier
49°
86°
10 0 20
Scale of Kilometres
1 2 3 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

Figure 1. Location map of the study area, scale 1:1 220 000.

CANADA ONTARIO
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This project is funded under the Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Canada-Ontario Economic and Regional Development Agreement.

prospecting classes, technical presentations and poster displays. The project is scheduled to run for 2 years and operate in conjunction with the Schreiber–Hemlo Resident Geologist Program. Funding is provided by the four-year Northern Ontario Development Agreement, a subsidiary agreement to the Canada-Ontario Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario. It is hoped this project will increase the geological data base of the Manitouwadge area and possibly assist in the discovery of new mineral resources to replace those currently being depleted. This report provides a brief summary of activities carried out in 1991. Details will be presented in the *Report of Activities 1991, Resident Geologists*, which is a Miscellaneous Paper format publication scheduled to be released in March, 1992, by the Ministry of Northern Development and Mines. An Open File Report documenting the metallic and/or economic mineral occurrences in the Manitouwadge area is scheduled for release in 1993.

Table 1. 1991 Property examinations, Manitouwadge Mineral Resource Geologist.

1. Agonzon Lake Mo occurrence
2. Armand Lake
3. Baarts-Donaldson Cu occurrence
4. Big Nama Creek Mine[1,3]
5. East Barbara Lake Sillimanite occurrence
6. Fairservice Zn occurrence
7. Faries Lake
8. Geco Division Mine[1,2]
9. Golden Giant Mine[2]
10. Hemlo Highway Section
11. Ice Cream Lake sulphide occurrence
12. Kusins Pb-Zn occurrence
13. Labrador Cu occurrence
14. Lampson Road Cu-Zn occurrence[4]
15. Lenora-Argentex
16. Lloyd Davis sulphide occurrence
17. Morley Lake Cu occurrence
18. Moshkinabi Lake
19. Otter Lake sulphide occurrence
20. Pinegrove Lake
21. Qued Resources
22. Rawluk Lake
23. Shabotik River Cu-Ni-PGE occurrence[1]
24. Snake Pit sulphide occurrence
25. Swill Lake
26. Taradale Cu occurrence
27. Taradale Lake graphite occurrence
28. Theresa Lake Cu occurrence[4]
29. Willecho Mine[1,3]
30. Williams Mine[2]
31. Willroy Mine[1,3]

[1] *visited during field trip conducted in 1991*
[2] *current producer*
[3] *past producer*
[4] *new occurrence*

MINERAL EXPLORATION AND MINING ACTIVITY

One base metal and three gold mines are currently producing in the project area. The Geco Division Mine (Noranda Inc.) in Manitouwadge has mined over 50 000 000 tons of copper and zinc ore since opening in 1957. At the current production rate of approximately 3 800 tons per day, ore reserves will be exhausted in 5 to 6 years (H. Lockwood, Geco Division Mine, personal communication, 1991). The Golden Giant Mine (Hemlo Gold Mines Inc.), the David Bell Mine (Teck-Corona Operating Corporation) and the Williams Mine (Williams Operating Corporation), all located in the Hemlo area, have been in production since 1985 and produced a total of approximately 1 347 300 ounces Au in 1990 (*Vancouver Stockwatch*, February 7 and 18, 1991). Based on 1990 data, the Hemlo deposit is estimated to contain a total (mined and remaining) of approximately 18 700 000 ounces of gold (Muir et al. 1991). The project area is being actively explored for gold and base metals by numerous prospectors and several major exploration companies including Noranda Inc. (Geco Division), Noranda Exploration Company Ltd., Granges Inc. and Newmont Exploration of Canada Ltd. Two new base metal occurrences (the Lampson Road Cu- Zn occurrence and the Theresa Lake Cu occurrence) have been discovered by prospectors in 1991 in mafic metavolcanic and metasedimentary rocks located approximately 30 km south of Manitouwadge (Figure 1). The discovery of the Theresa Lake Cu occurrence resulted from funding provided by the Ontario Prospectors Assistance Program (OPAP). Assay results are pending.

FIELD WORK

At the time of writing, 31 properties had been visited and examined (Table 1; Figure 1). These comprise 19 base metal properties, 9 gold properties, 1 platinum group element (PGE) property, 1 molybdenum property and 1 graphite property. A total of 272 grab samples were collected and submitted for multielement analysis to determine metal content and chemical alteration, where applicable. Property-scale geological mapping was performed on several of the properties.

OTHER ACTIVITIES

Exploration-company personnel were given tours of the Shabotik River Cu-Ni-PGE property, in Shabotik Township, and of the Geco Division, Willroy, Big Nama Creek and Willecho mines properties, near Manitouwadge. Assistance was provided to Geological Survey of Canada geologists I. Kettles and E. Zaleski who both initiated projects in the Manitouwadge area in 1991. I. Kettles is studying the Quaternary geology of the Manitouwadge area, and E. Zaleski is studying the metamorphic petrology of the base metal deposits in the same area. A flake-graphite occurrence was discovered in the Taradale Lake area, approximately 50 km north of Manitouwadge, and was brought to the attention of P. Hinz, Industrial Minerals Geologist, Regional Mineral Resources Section, Thunder Bay. Exploration in the Manitouwadge area was promoted through numerous informal discussions with prospectors and exploration-company personnel.

RECOMMENDATIONS FOR EXPLORATION

The discovery of the Manitouwadge and Hemlo mining camps has proven that caution and a fair bit of patience are required when assessing mineral showings in amphibolite-facies terranes. The project area has a history of unimpressive-looking mineral occurrences. In addition, deformation, metamorphism and hydrothermal alteration have acted to obscure high-potential rocks, thus, making exploration targets difficult to identify. It is suggested that all sulphide occurrences in the project area, regardless of size or lateral extent, be fully investigated. Occurrences of alteration minerals or their metamorphic equivalents, such as garnet, anthophyllite and sericite, merit investigation, whether or not they occur with sulphides.

Gold deposits in the Hemlo area are hosted by sericite-muscovite-pyrite schists in amphibolite-facies rocks and appear to have a genetic association with quartz-porphyritic, felsic intrusive and volcanic rocks (Schnieders et al. 1991). Such rocks also occur in the Manitouwadge area, and, therefore, these more traditional base metal targets should be explored for their gold potential. Pyritic, quartz-eye sericite schists containing green mica occur on the Armand Lake property, located approximately 4 km west of Theresa Lake. The similarity between these rocks and those associated with the Hemlo deposit warrants further exploration for gold in this area.

Recent geological mapping of the Manitouwadge area by Williams and Breaks (1989, 1990a, 1990b) has identified areas of metasedimentary and metavolcanic gneisses or "ghost greenstone" previously denoted as granitic rocks by earlier workers. These areas should be thoroughly investigated to determine their gold and base metal potential. The possibility exists that volcanogenic massive-sulphide deposits similar to those in the Manitouwadge and Winston Lake camps may occur in the Theresa Lake–Dotted Lake–Black River area (Schnieders et al. 1991). The recent discovery of 2 new base metal occurrences (the Lampson Road Cu-Zn and the Theresa Lake Cu occurrences) in the metavolcanic-metasedimentary rock sequence extending west from Theresa and Dotted lakes serves to illustrate the potential of this area. Recently-released geochemical data (Friske et al. 1991) indicate anomalous concentrations of Au, Cu and Zn in lake sediment and water samples collected from the Theresa, Dotted and Pinegrove lakes areas. Anomalous concentrations of Au, Cu and Zn also occur in lake sediment and water samples collected from the Flanders Lake area, located approximately 45 km northeast of Manitouwadge. All such anomalies should be thoroughly investigated to determine the potential for gold and base metal mineralization in the surrounding area. A summary of high-potential areas for gold, base metal and platinum group element mineralization in the project area is given by Schnieders et al. (1991).

ACKNOWLEDGMENTS

The author is indebted to the many prospectors and geologists who provided assistance during the course of this project. Special thanks are given to B. Schnieders and M. Smyk who supplied invaluable information, conducted numerous field trips and assisted in several property examinations. Several exploration and mining companies and their personnel provided permission for access to various mineral properties, and the author's gratitude is expressed to all. Thanks are also extended to exploration personnel from Noranda Inc. (Geco Division) and Noranda Exploration Company Ltd. who provided access to proprietary information and who provided assistance in the field. T. Oja provided competent and gratefully appreciated assistance in the field for the majority of the summer. B. Nelson provided technical support and lapidary services, B. Schnieders and M. Smyk reviewed and edited this report and C. Komar reviewed and typed the manuscript.

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——1990a. Geological studies in the Manitouwadge–Hornepayne region; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.41–47.

——1990b. Geology of the Manitouwadge–Hornepayne area; Ontario Geological Survey, Open File Map 142, scale 1:50 000.

55. Thunder Bay—Atikokan Area Digital Mineral-Exploration Inventory

J. Bellinger

Data Folio Geologist, Thunder Bay District, Northwestern Ontario

INTRODUCTION

Indexes of mineral-exploration data in the Thunder Bay–Atikokan area have been converted from paper-records into a digital format that covers NTS areas 52 A and 52 B (*see* Figure 1). The project is jointly funded by the four-year Canada—Ontario 1991 Northern Ontario Development Agreement, a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario. The main objective of the project is to facilitate mineral exploration by providing a complete and up-to-date index of exploration data over the entire area.

The Thunder Bay–Atikokan area has a high mineral potential. As a result, there is a large amount of exploration activity which is documented in both the assessment files and the mineral-deposit files. The present assessment file inventory system consists of overlays (simple compilations of property outlines inked onto mylar and overlaying this onto a paper claim map) as well as published and unpublished Geological Data Inventory Folios (GDIFs) which are more-comprehensive, nondigital data compilations. Coverage of the area was provided by 19 unpublished GDIFs and 54 overlays. With the creation of the digital inventory, uniform coverage of the area is available in an easily revisable format. The mineral-deposit files are presently indexed via a card-based file system.

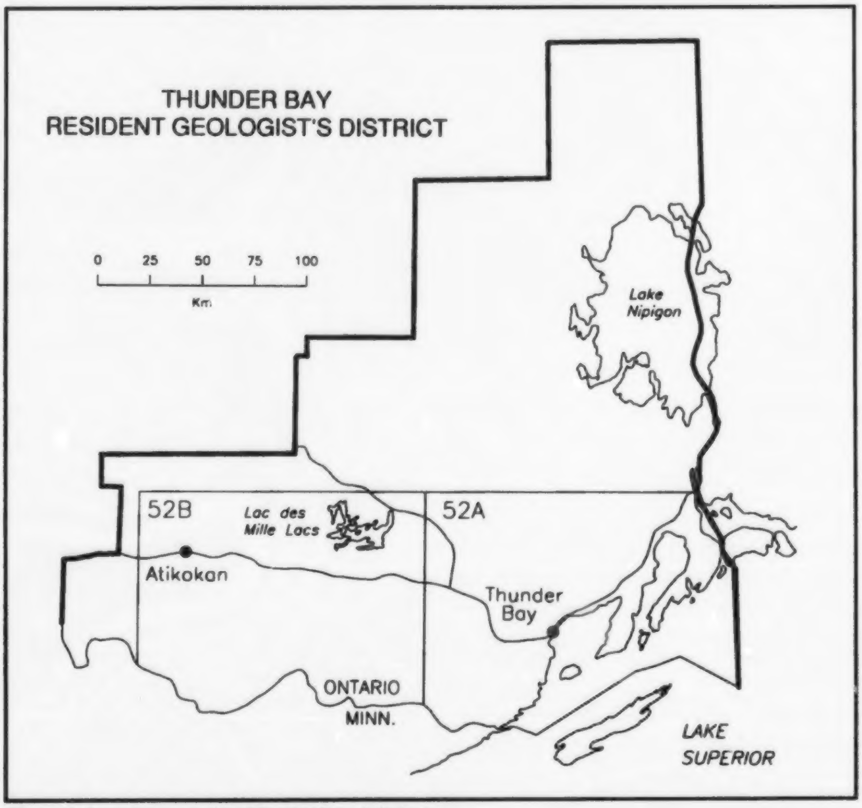

Figure 1. Location map of the Thunder Bay–Atikokan area.

CANADA ONTARIO

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This project is funded under the Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Canada-Ontario Economic and Regional Development Agreement.

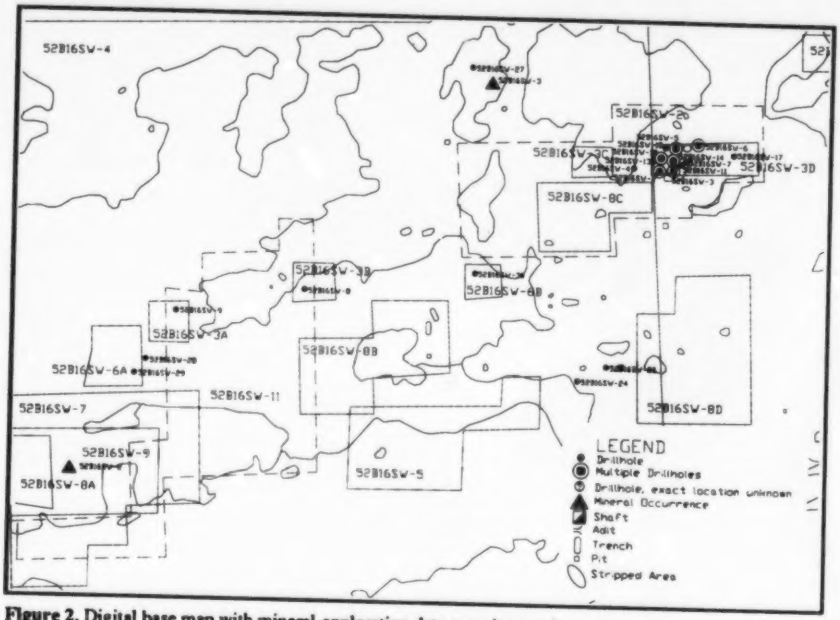
52B16SW-4
52B16SW-2D
52B16SW-3C
52B16SW-3D
52B16SW-8C
52B16SW-3B
52B16SW-8B
52B16SW-3A
52B16SW-6A
52B16SW-8B
52B16SW-11
52B16SW-7
52B16SW-9
52B16SW-8A
52B16SW-5
52B16SW-8D
LEGEND
Drillhole
Multiple Drillholes
Drillhole, exact location unknown
Mineral Occurrence
Shaft
Adit
Trench
Pit
Stripped Area

Figure 2. Digital base map with mineral-exploration data superimposed.

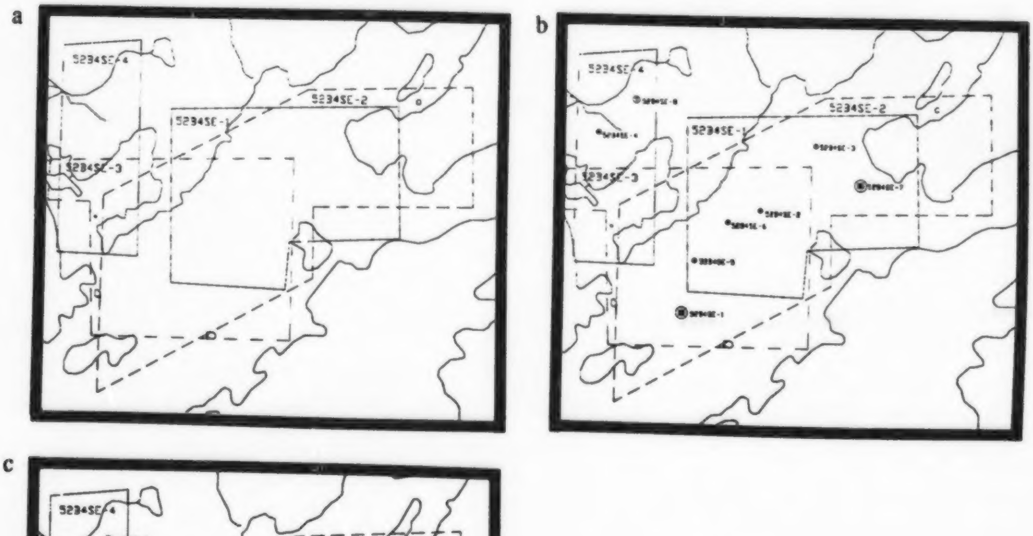
a
52B4SE-4
52B4SE-2
52B4SE-1
52B4SE-3
b
52B4SE-4
52B4SE-2
52B4SE-1
52B4SE-3
c
52B4SE-4
52B4SE-2
52B4SE-1
52B4SE-3
LEGEND
Drillhole
Multiple Drillholes
Drillhole, exact location unknown
Mineral Occurrence
Shaft
Adit
Trench
Pit
Stripped Area

Figure 3. Digital base map showing the following: a) exploration areas; b) exploration areas with drilling; and c) exploration areas with drilling, mineral occurrences, stripping and trenching.

INVENTORY CREATION

Digital-Map Creation

Mineral-exploration data has been superimposed onto digital topographic-base maps using the computer-aided drafting software AutoCAD®. The base maps are separated along NTS divisions, such as 52 A/4 or 52 B/10, and consist of topographic data including such features as roads, lakes, rivers, railways among others. As a function of AutoCAD®, each type of data is entered on a separate layer so that they can be individually manipulated through their visibility (layers may be shown or turned off), colour and line type. Layers which have been entered to date include areas of exploration (an outline of areas where assessment work has been applied), mineral occurrences, and drilling, stripping and trenching activities. The information is defined on screen by unique symbols, each with an associated reference number linking it to the data base (*see* Figure 2). The reference number has been created based upon the NTS area.

Data-Base Creation

The data base has been created using dBase IV®. Information included in the data base for areas of exploration consists of the company and/or individual who did the work, the work completed and the year. For drilling operations, the company name and company drill-hole number are given. For mineral occurrences, the commodity is named and the source(s) where the occurrence is mentioned is listed. For each piece of information, the reference number is listed, linking the data base to the map.

BENEFITS

With the digital inventory, clients will have access to current data compilations to assist them in their research. This will reduce the amount of time spent by the client doing initial research on an area.

With the map data entered on separate layers which can be turned "off and on", only the information selected will be displayed (*see* Figure 3). This will result in easier searches for those needing specific information only. With the use of a plotter, custom maps at both standard and nonstandard scales would be available.

With a digital index, the addition of new information is made much easier and quicker. This will be advantageous in keeping the inventory current and will reduce staff time required for compilation.

SUMMARY

The digitization of mineral-exploration data in the Thunder Bay–Atikokan area has produced a workable inventory with a consistent level of coverage over the area. Information which has been entered to date includes areas of exploration, mineral occurrences, and drilling, stripping and trenching activities. The inventory is amenable to the addition of other geotechnical data to provide a more detailed compilation in the future.

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Conversion Factors for Measurements in Ontario Geological Survey Publications

Conversion from SI to Imperial			**Conversion from Imperial to SI**		
SI unit	*Multiplied by*	*Gives*	*Imperial unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1 016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

1 ounce (troy per ton) (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

***Note:** Conversion factors that are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.*

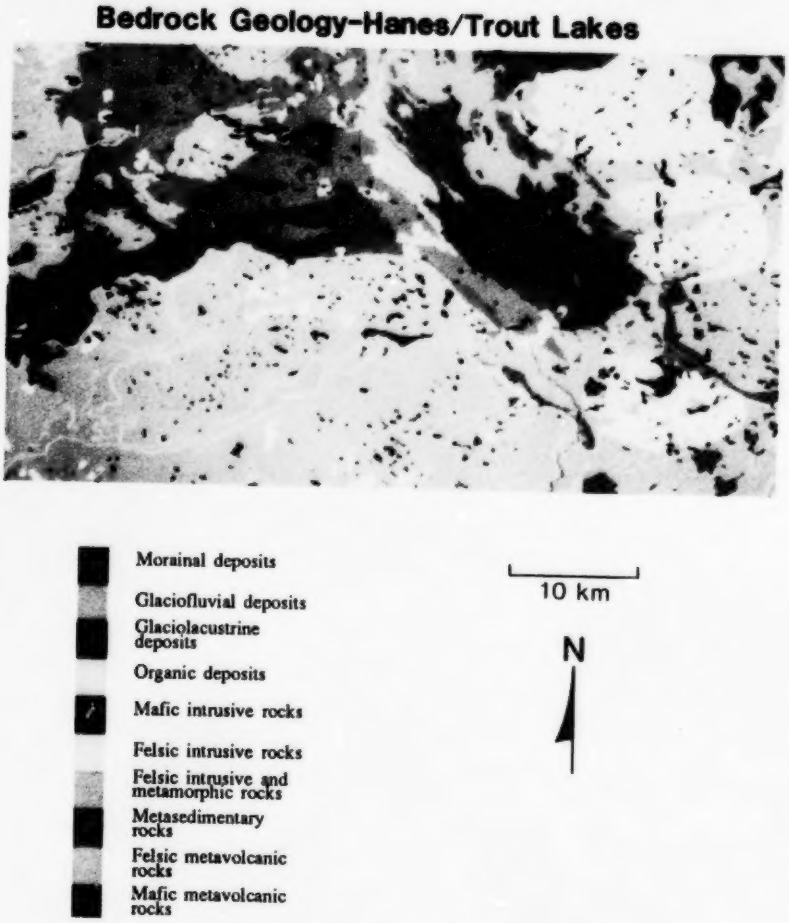
Bedrock Geology-Hanes/Trout Lakes
Morainal deposits
Glaciofluvial deposits
Glaciolacustrine deposits
Organic deposits
Mafic intrusive rocks
Felsic intrusive rocks
Felsic intrusive and metamorphic rocks
Metasedimentary rocks
Felsic metavolcanic rocks
Mafic metavolcanic rocks
10 km
N

Plate I. Digitized geological map of the Trout Lake–Haines Lake study area (modified from Forteque and Vida 1989, 1990).

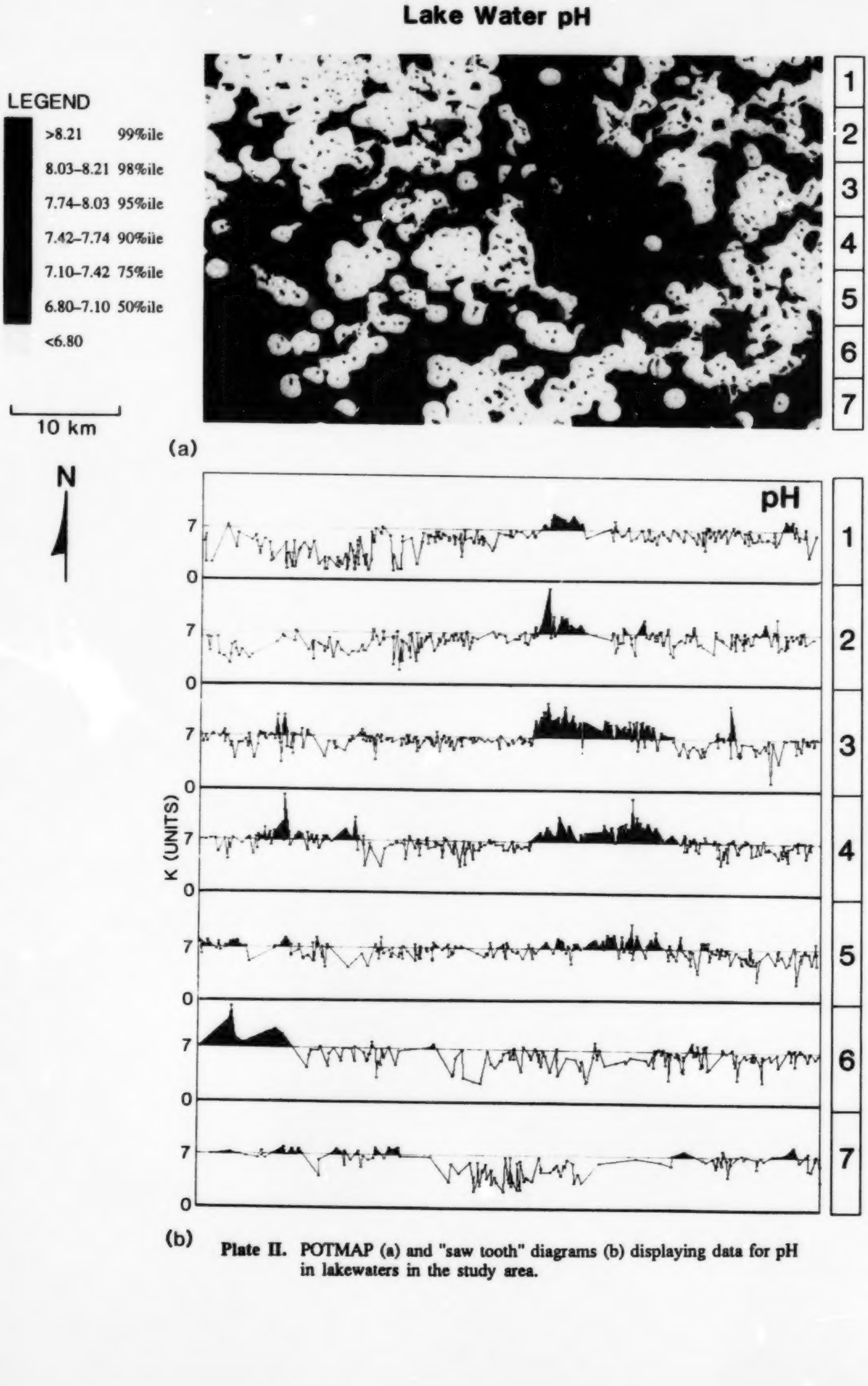
Lake Water pH
LEGEND
>8.21 99%ile
8.03–8.21 98%ile
7.74–8.03 95%ile
7.42–7.74 90%ile
7.10–7.42 75%ile
6.80–7.10 50%ile
<6.80
10 km
N
(a)
1
2
3
4
5
6
7
pH
K (UNITS)
7
0
(b)

Plate II. POTMAP (a) and "saw tooth" diagrams (b) displaying data for pH in lakewaters in the study area.

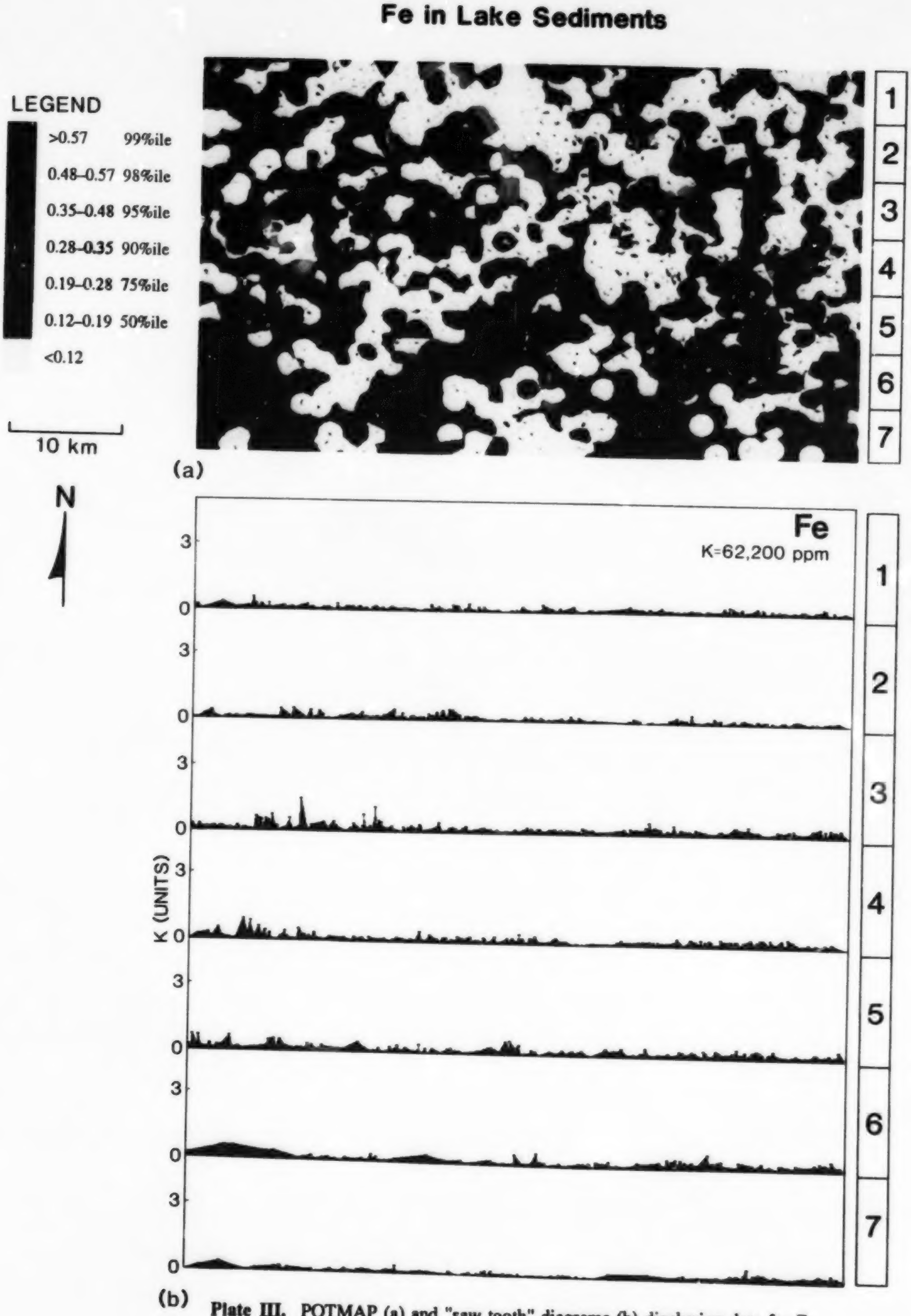
Fe in Lake Sediments
LEGEND
>0.57 99%ile
0.48–0.57 98%ile
0.35–0.48 95%ile
0.28–0.35 90%ile
0.19–0.28 75%ile
0.12–0.19 50%ile
<0.12
10 km
N
(a)
1
2
3
4
5
6
7
Fe
K=62,200 ppm
3
0
K (UNITS)
(b)

Plate III. POTMAP (a) and "saw tooth" diagrams (b) displaying data for Fe in 1856 pre-Ambrosia lake sediments collected from the study area.

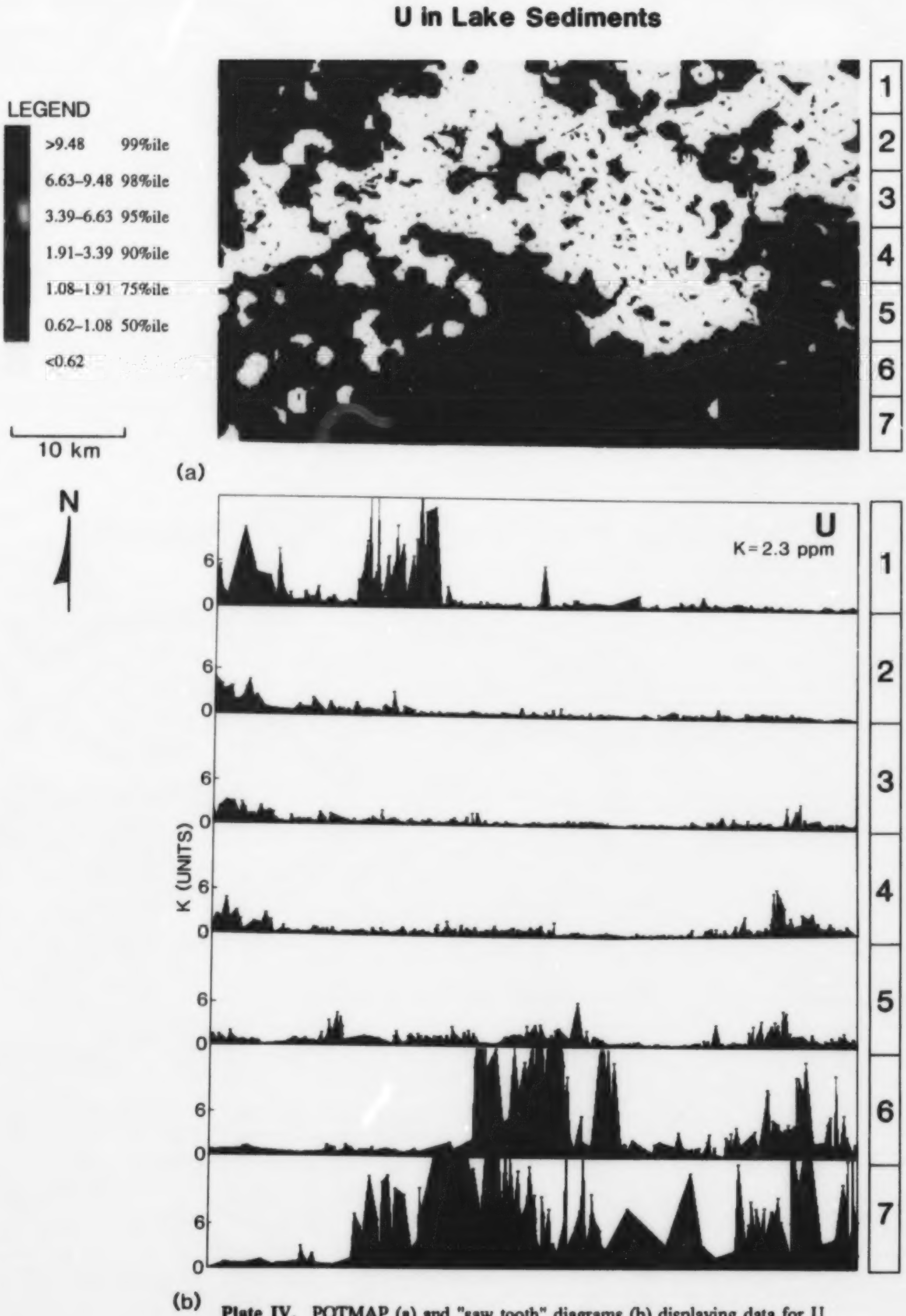
U in Lake Sediments
LEGEND
>9.48 99%ile
6.63–9.48 98%ile
3.39–6.63 95%ile
1.91–3.39 90%ile
1.08–1.91 75%ile
0.62–1.08 50%ile
<0.62
10 km
N
(a)
1
2
3
4
5
6
7
U
K=2.3 ppm
K (UNITS)
6
0
(b)

Plate IV. POTMAP (a) and "saw tooth" diagrams (b) displaying data for U in 1856 pre–Ambrosia lake sediments collected from the study area.

As in Lake Sediments

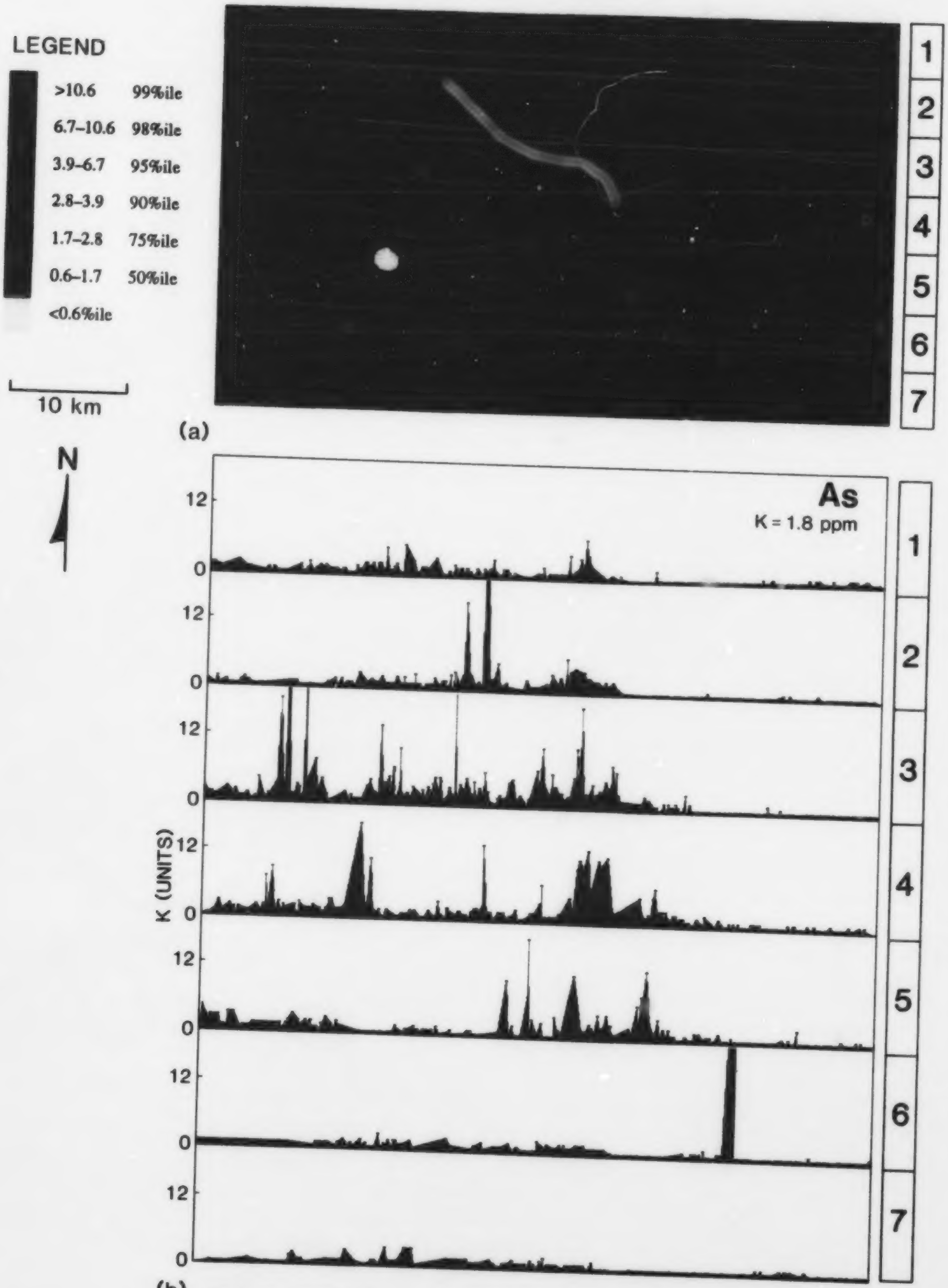
LEGEND
>10.6 99%ile
6.7–10.6 98%ile
3.9–6.7 95%ile
2.8–3.9 90%ile
1.7–2.8 75%ile
0.6–1.7 50%ile
<0.6%ile
10 km
N
(a)
1
2
3
4
5
6
7
As
K = 1.8 ppm
K (UNITS)
12
0
(b)

Plate V. POTMAP (a) and "saw tooth" diagrams (b) displaying data for As in 1856 pre–Ambrosia lake sediments collected from the study area.

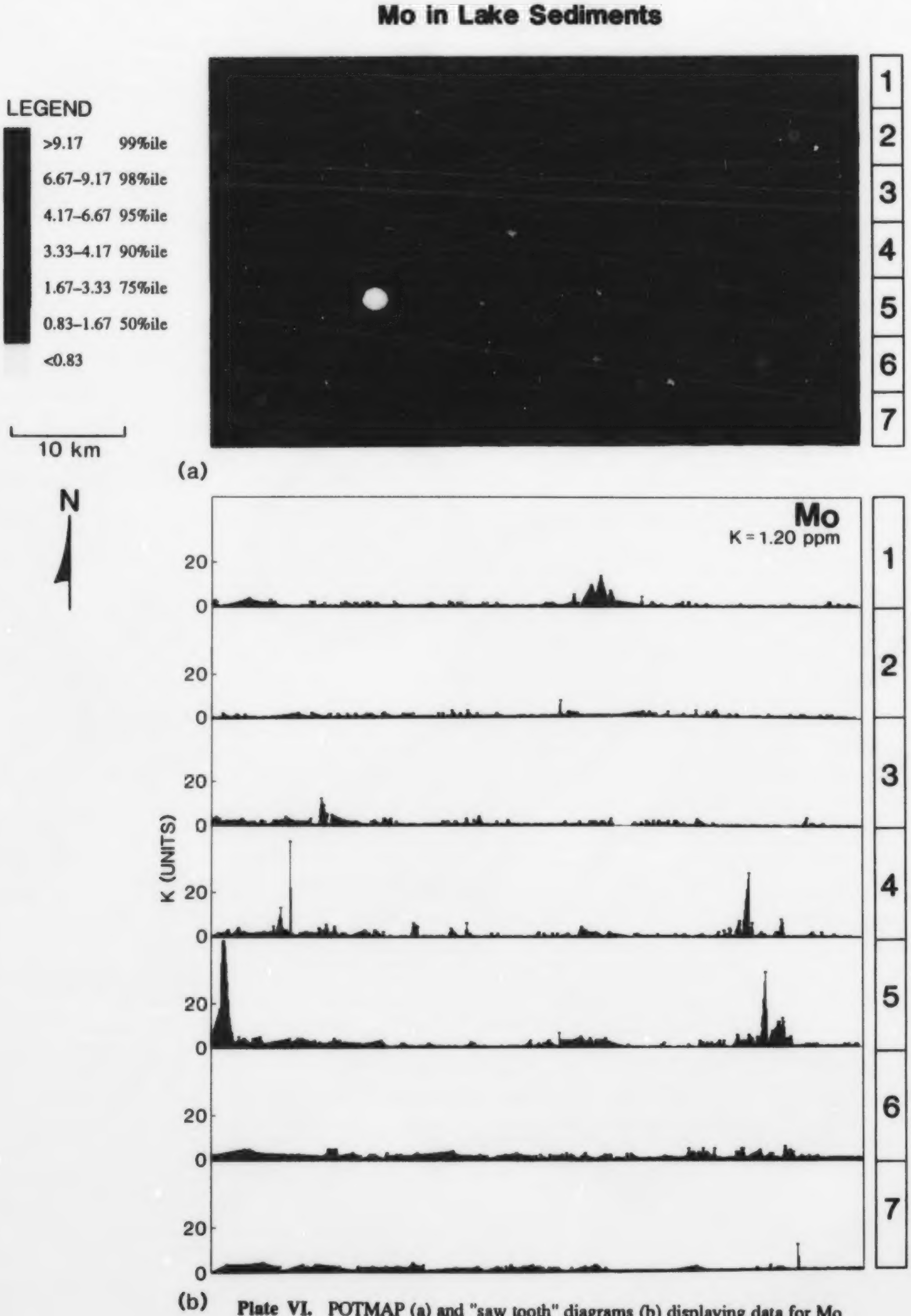
Mo in Lake Sediments
LEGEND
>9.17 99%ile
6.67–9.17 98%ile
4.17–6.67 95%ile
3.33–4.17 90%ile
1.67–3.33 75%ile
0.83–1.67 50%ile
<0.83
10 km
N
1
2
3
4
5
6
7
(a)
Mo
K = 1.20 ppm
K (UNITS)
20
0
(b)

Plate VI. POTMAP (a) and "saw tooth" diagrams (b) displaying data for Mo in 1856 pre–Ambrosia lake sediments collected from the study area.

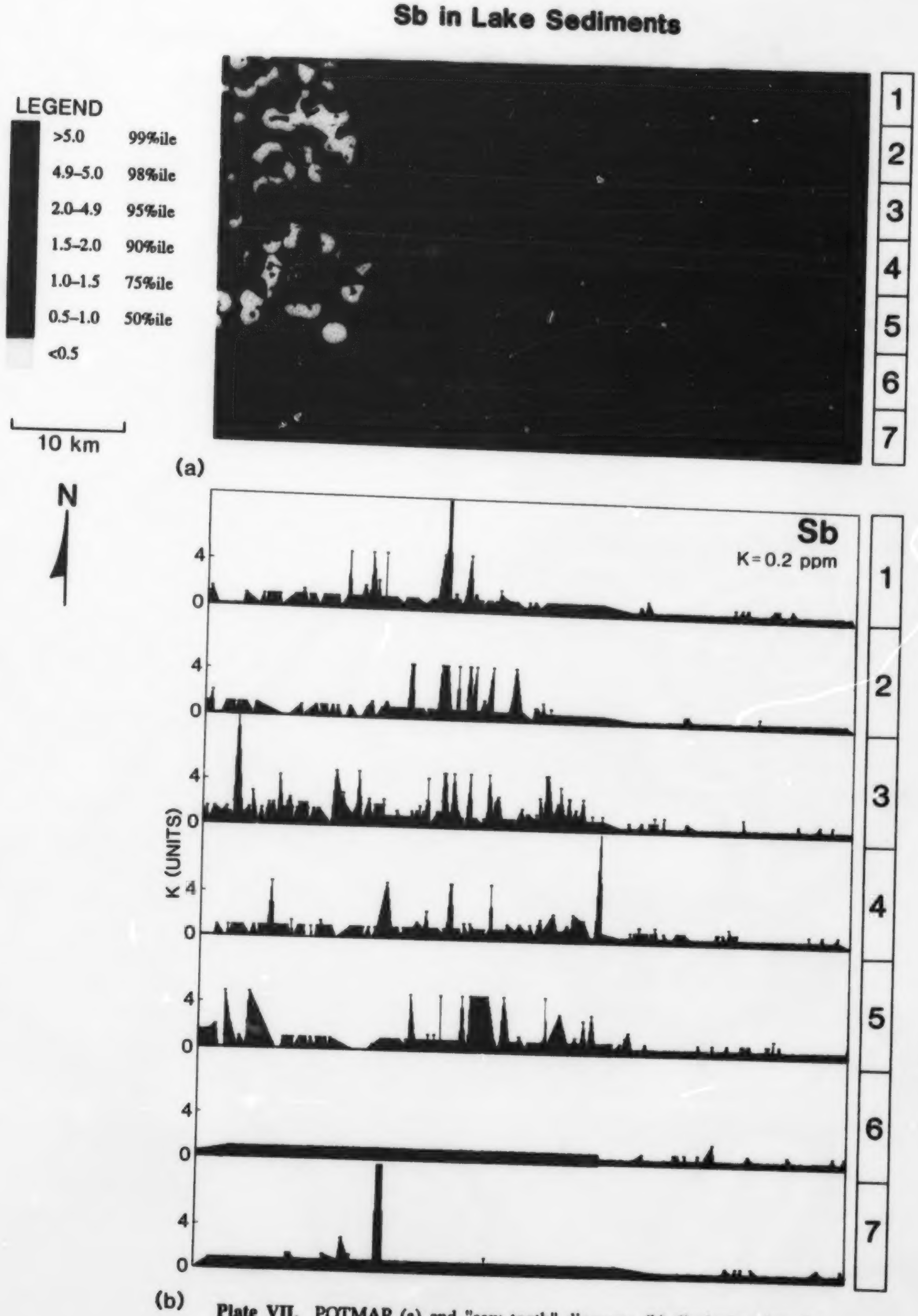
Sb in Lake Sediments
LEGEND
>5.0 99%ile
4.9–5.0 98%ile
2.0–4.9 95%ile
1.5–2.0 90%ile
1.0–1.5 75%ile
0.5–1.0 50%ile
<0.5
10 km
N
(a)
1
2
3
4
5
6
7
Sb
K=0.2 ppm
K (UNITS)
4
0
(b)

Plate VII. POTMAP (a) and "saw tooth" diagrams (b) displaying data for Sb in 1856 pre–Ambrosia lake sediments collected from the area shown in the geological map (Plate I).